



A User's Guide for the Spacecraft Fire Safety Facility

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A User's Guide for the Spacecraft Fire Safety Facility

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1. Introduction

The Spacecraft Fire Safety Facility (SFSF) is a test facility that can be flown on NASA's reduced gravity aircraft to perform various type of combustion experiments under a variety of experimental conditions. To date, this facility flown numerous times on the aircraft and has been used to perform experiments ranging from an examination of the effects transient depressurization on combustion, to ignition and flame spread. A list of publications/presentations based on experiments performed in the SFSF is included in the reference section.

This facility, shown in Figure 1, consists of five main subsystems: combustion chamber, sample holders, gas flow system, imaging system, and the data acquisition/control system. Each of these subsystems will be reviewed in more detail in the following sections. These subsystems provide the experiment operator with the ability to monitor and/or control numerous experimental parameters.

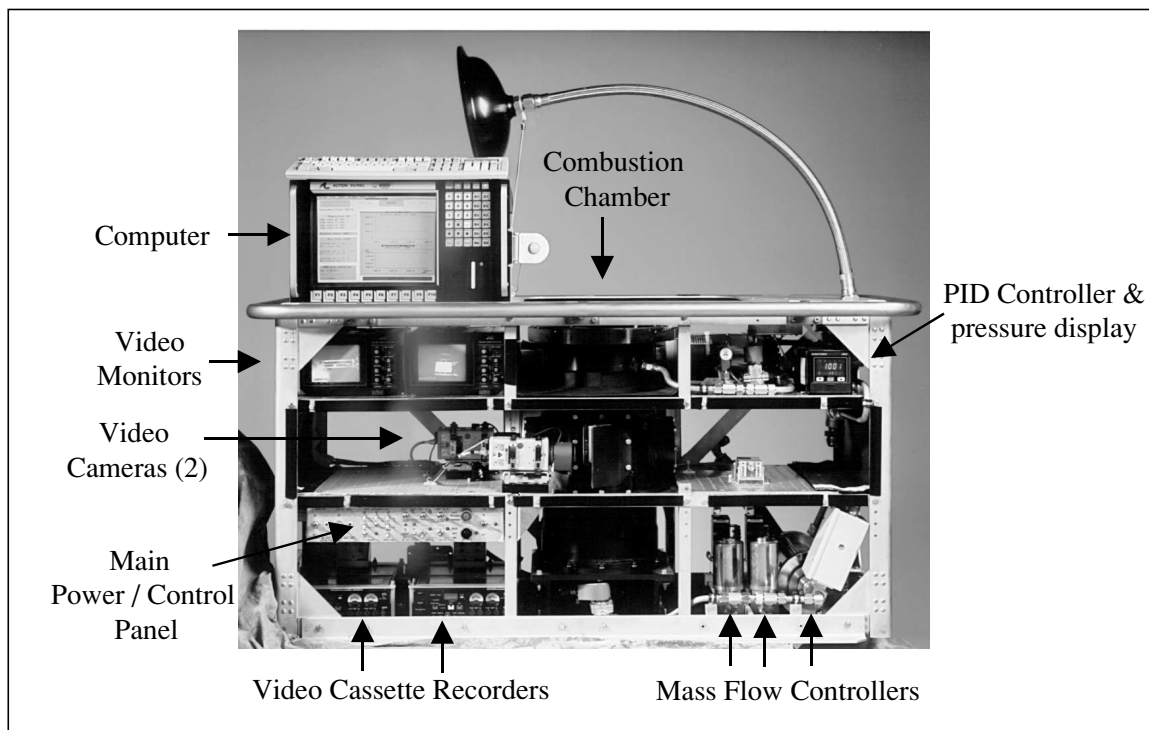


Figure 1 - Spacecraft Fire Safety Facility (SFSF)

2. Combustion Chamber

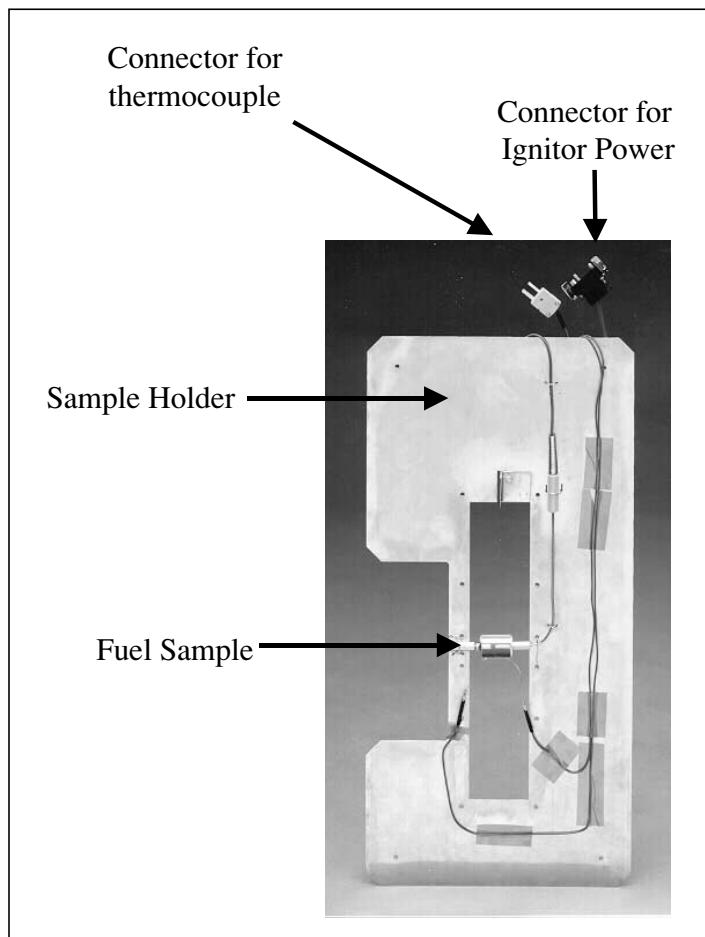
The facility has an aluminum combustion chamber that has a diameter of 25.4 centimeters and a height of 51 centimeters, with a volume of 25.8 liters. The chamber's operating pressure range is vacuum to three atmospheres (44.1 psia). The lid is removable, as shown in Figure 1, which permits access to the interior of the combustion chamber; the lid is secured in place with a strap

to prevent it from floating away during periods of low-gravity. In the closed configuration, the lid sits on the combustion chamber and is secured into place using a v-band clamp. (An o-ring placed in a groove between the chamber and the lid provides a pressure seal. Three window ports along the chamber wall provide views of the interior of the chamber; two side mounted and one on the front of the rig. The front window is rectangular: 10.16 cm wide by 15.24 cm in height. The side windows are round with a 10.46 cm diameter.

The facility is equipped with power and thermocouple passthroughs that allow electrical power and thermocouple signals to be passed in and out of the chamber without affecting the chamber's pressure seal. The current configuration supports four type K thermocouples and four 28 VDC power inputs. In unusual situations, it is also possible route a power and/or signal cable through the window port by replacing the optical window material with an aluminum blank.

3. Sample Holders

The current sample holders are a 0.04 cm thick sheet of stainless steel, 25 centimeters wide by 47 centimeters in length. There are two rectangular cutouts in the plate, with the first being in the center of the sheet. This allows for mounting of a combustion sample, as shown in Figure 2. (Other possible test configurations with this holder include mounting a thin fuel sample along the edges of the center cut-out for flame spread studies.) The second cutout is required to reduce any blockage of the field of view by the sample holder.



Before each experiment the sample holder is lowered into the chamber on a set of guide rails mounted to the interior chamber wall, aligning the samples with the center of the windows. Any thermocouple and igniter wires are connected to a pass-through on the inside wall of the combustion chamber. (The connectors are shown in Figure 2.)

Figure 2 – Sample holder with cylindrical fuel sample, thermocouple probe and igniter leads

4. Flow System

The facility's gas flow system consists of an inlet and outlet segment, separated by the combustion chamber (See Figure 3). High-pressure gas bottles provide pressurized gas that enters the inlet portion of the system through one of three mass flow controllers. Two of the controllers have a flow range of 25 to 500 standard liters per minute (SLPM) with an accuracy of $\pm 1\%$ of

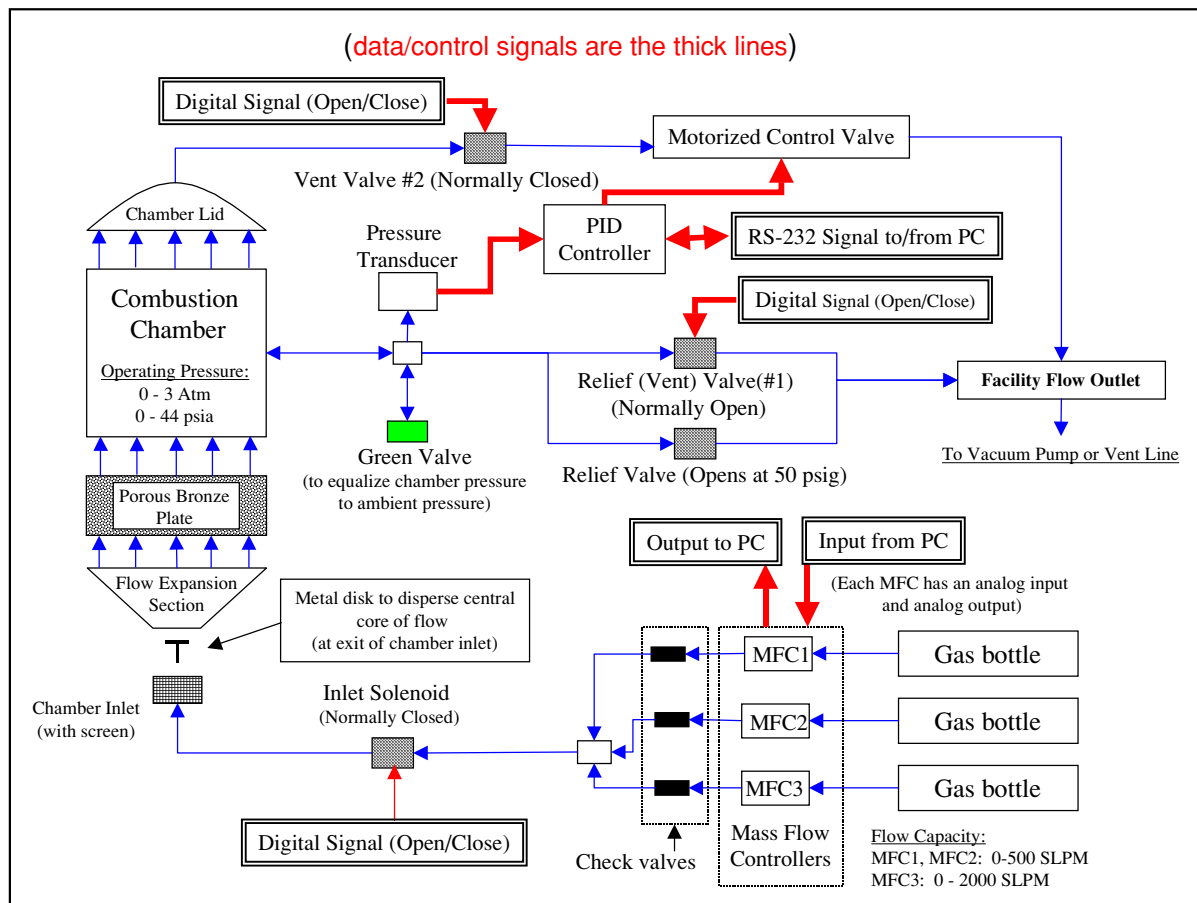


Figure 3 - Flow system schematic

full scale (± 5 SLPM). The third controller has a flow range of 100 to 2000 SLPM with an accuracy of $\pm 1\%$ of full scale (± 20 SLPM). Although not currently configured in the control software, multiple flow controllers could be used to adjust the gas mixture during a test.

From each of the mass flow controllers, the flows pass through individual check valves, into a common inlet solenoid valve that opens when energized, and closes when de-energized. The gas flow then enters the inlet section of the combustion chamber, passing through a series of screens and an elbow that turns the flow vertically. The flow passes around a one-inch metal deflector disk designed to eliminate a central core of flow within the chamber. Finally, the flow passes through a one-inch thick porous metal plate that produces a pressure drop causing plug flow in the chamber.

Assuming a plug flow at atmospheric pressure, the maximum velocity that can be obtained in the chamber using either controller 1 or 2 is 17 cm/s, which corresponds to 500 SLPM. This is calculated using the flow equations in Appendix F. Using controller 3, the maximum velocity that can be obtained in the chamber with a pressure of one atmosphere is 70 cm/s (2000 SLPM). However, this high flow velocity will use an enormous amount of gas (2000 liters per minute) and this flow volume may cause a rapid rise in the chamber pressure as the outlet valve opening may be too small.

The flow within the combustion chamber is examined using a hot wire anemometer and flow visualization techniques. Small drops of (train smoke) oil are placed on a thin wire that is placed near the bottom of the combustion chamber. As the wire is resistively heated, the smoke oil evaporates and is carried downstream by the forced flow, creating the smoke traces. Images of streamlines recorded during flow visualization tests show a uniform flow within the chamber (See Figure 4). The radial velocity profile is measured with a hot wire anemometer at the vertical midpoint in the chamber. The measured profile is nearly constant near the centerline and increases slightly near the chamber wall (See Figure 5). At a flow rate of 300 standard liters per minute, which corresponds to a plug-flow velocity of 10.6 cm/s, the volumetric flow rate computed from the measured velocity profile differs from the actual flow rate by 11%. The difference in the volumetric flow rates is probably caused by errors in the velocity data near the chamber wall, which occurs because the hot wire could not measure data near the walls due to the probe design. The velocity data near the walls is approximated using the measured data and a no-slip condition at the wall.

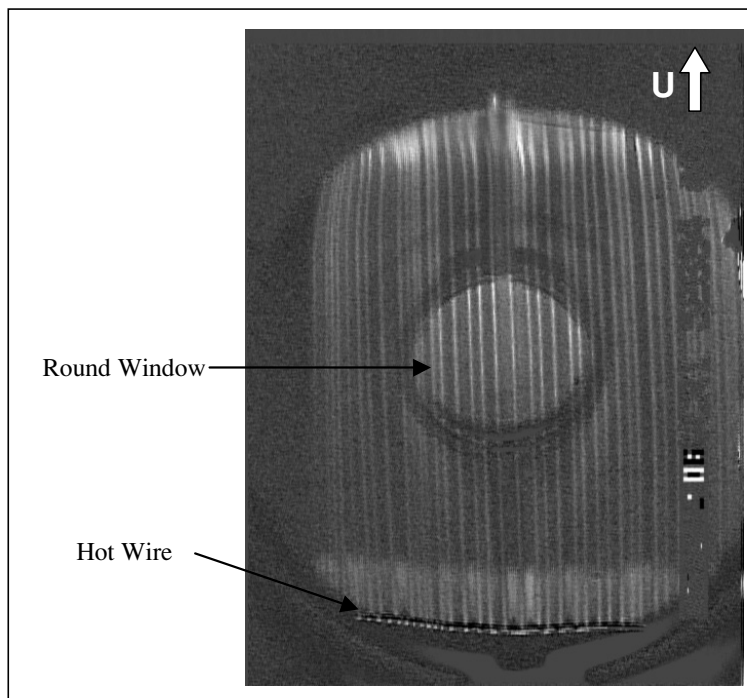


Figure 4 - Flow Streamlines within the combustion chamber

The pressure in the combustion chamber is measured by a pressure transducer that has a range of 0 to 3.4 atmospheres (50 psia) with a measurement error less than 1×10^{-3} atmospheres. The pressure in the chamber is displayed in millibars (1013 millibar = 1 Atm) on a PID (Proportional Integral Derivative) controller (see Figure 1). This unit controls the pressure within the chamber by opening or closing a motorized valve located downstream of the combustion chamber (as shown in the schematic in Figure 3). The pressure in the chamber can be changed either manually using the

PID controller's front panel, or automatically via computer control. In the computer mode, the PC commands the controller into program mode, which changes the chamber pressure set point

as a step or ramp function. (The pressure set point is the desired pressure that the controller aims to match.) If ramping the pressure set point, the pressure changes at a constant rate (dP/dt) set by the operator using the controller's front panel.

In normal operating conditions, the gas within the combustion chamber exits through the chamber lid, passing through a vent valve solenoid, a motorized control valve, and then exits the facility. Like the inlet solenoid, this valve is normally closed and only open when energized. (Table C1 in Appendix C details the powered/unpowered states of the solenoids.) The motorized valve utilizes a sliding plate mechanism in which a pair of machined plates have a series of openings in which the gas passes through. Using plates with different size openings, the maximum flow capacity of the facility can be altered. Currently, three pairs of plates are available, with flow opening sizes corresponding to flow coefficients (C_v) of 0.85, 6.4, and 9.5. The plates cannot be changed during flight, as this process requires disassembling the motorized control valve and some of the flow hoses.

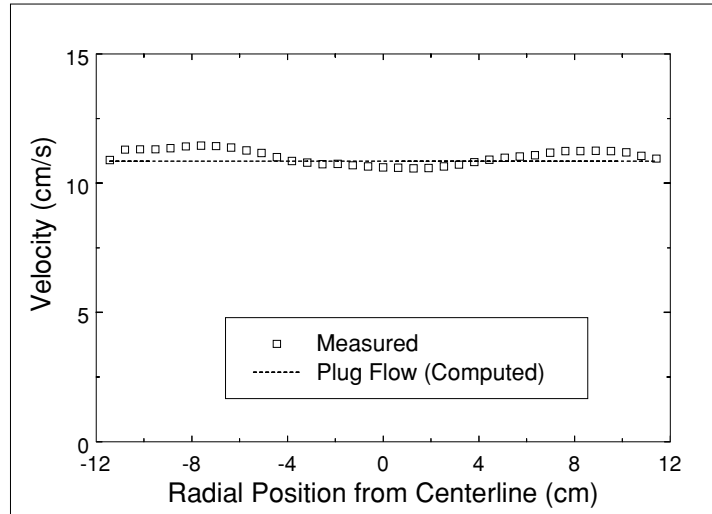


Figure 5 - Radial Flow Profile at 300 SLPM

After passing through the control valve, the exhaust gas can be sent to the inlet of a vacuum pump. The vacuum pump is used in experiments that require a reduced chamber pressure in low-gravity. The pump has a capacity of 500 SLPM at one atmosphere and a flow capacity of 50 SLPM at 0.1 atmospheres. The exhaust from the vacuum pump is sent to the overboard vent line on the aircraft. (The overboard vent line is a connection that is open to atmospheric pressure outside of the aircraft.) In experiments not using the vacuum pump, the flow from the motorized control valve is sent directly to the overboard vent.

In emergency situations, such as loss of power to the facility, or a pressure reading above 3447 millibar (3.4 Atm = 50 psia), the inlet solenoid and vent valve #2 are unpowered (closed) while the relief valve (vent #1) opens (see Figure 3). This prevents any additional gas from entering the chamber and vents any gas in the combustion chamber. As a secondary backup, a spring-loaded relief valve opens if the chamber pressure exceeds 4.4 Atm (64.7 psia = 50 psig). This flow path bypasses the solenoid valves and the motorized control valve as shown in Figure 3. The flow system is also equipped with a manual valve (green handle) that can be used to equalize the pressure in the chamber with the ambient pressure. This is important when changing samples in flight as the cabin and chamber pressures will, most likely, not be equal.

Using the mass flow controllers and the PID controller along with the PC control system, the facility can provide a constant flow of gas within the chamber at a constant pressure. In addition, the facility can provide a constant gas velocity within the chamber for tests that require a variable pressure. More information on this option is provided in Appendices A and F.

5. Imaging System

The rig is equipped with imaging hardware that consists of two color CCD video cameras, two SVHS VCRs, two color monitors, and two time code generators. The cameras can be placed to provide two orthogonal views of the experiment. One view is taken from a side window while the other is taken from the front window using a mirror that is mounted to the window frame.

The video signal from the cameras is sent through the time code generators, into the VCRs, and then displayed on the monitors. The time code generators place a continuous time stamp on the video signal that is recorded along with the experiment images. The time code generators are started simultaneously using digitally controlled relays to provide an identical time stamp on both recorded images. A wiring schematic of the imaging system is shown in Figure 6.

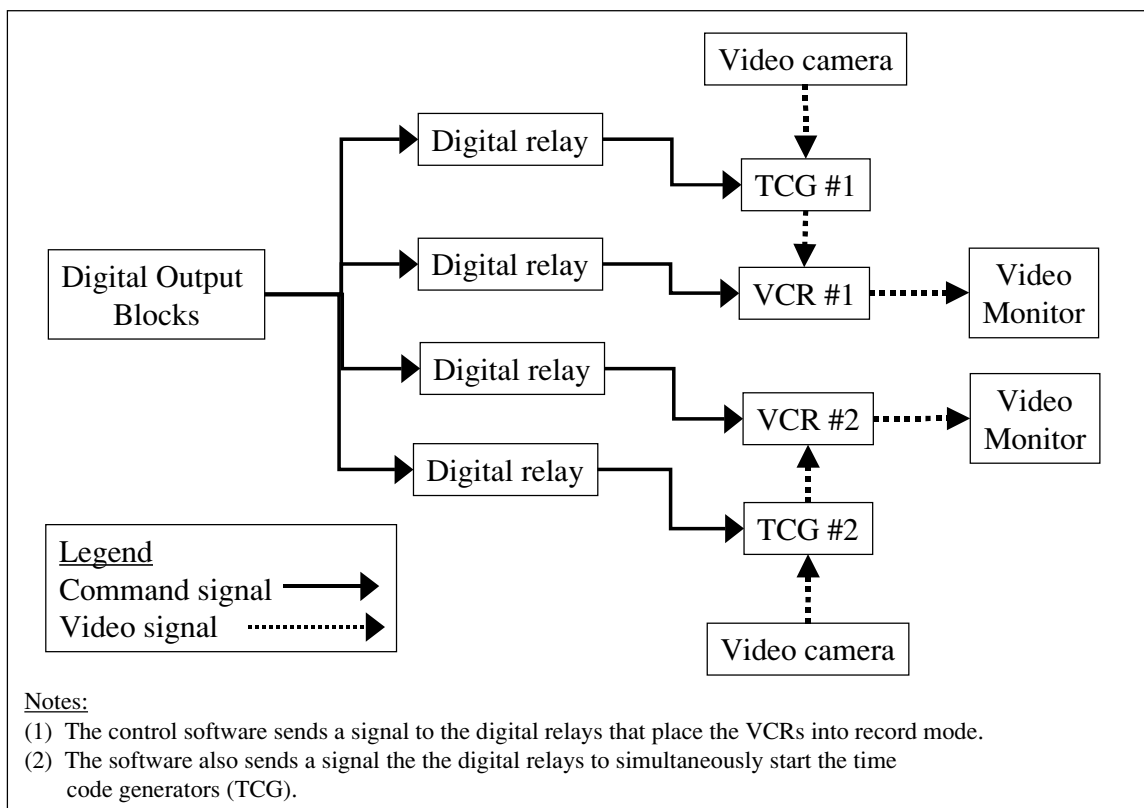


Figure 6 - Imaging system wiring schematic

6. Main Control / Power Panel

The facility's main control / power panel is located just below the optical shelf on the left side of the rig, as shown in Figure 1. The panel's controls includes switches for main power, 120 VAC power, 28 VDC auxiliary, an external lamp, as well as power switches for the: computer, igniter, accelerometers, cameras, and solenoids (see Figure 7). The igniter can be placed into one of two modes, either off or computer controlled; the igniter cannot be activated manually. Using the control panel the solenoids can be placed into one of three modes: off ('Center'), manually energized ('Down'), or computer controlled ('Up'). The accelerometer controls also allow the facility operator to energize the units, send a zero (0) voltage output signal, or adjust the gain on the signal (See Figure 8). The gain switches on the control panel set the gain as shown in Table 1. Normally, the gain is set to unity for each accelerometer channel.

A1	A0	GAIN
0	0	1
0	1	10
1	0	100
1	1	1000

Table 1 – Accelerometer Gain Settings

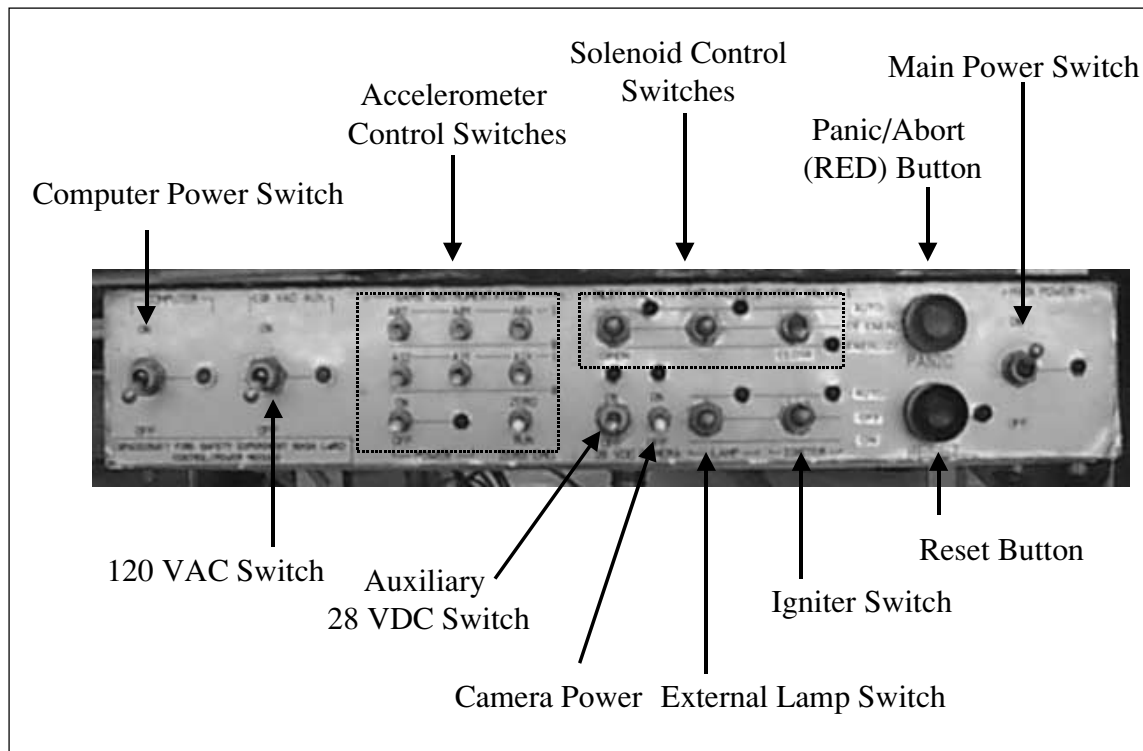


Figure 7 - Main power/control panel

The (red) Panic/Abort button on the power/control panel can be used to stop an experiment in an emergency situation. When depressed, this button automatically closes the inlet solenoid, closes vent valve #2, opens relief valve #1, and de-energizes the igniter circuit. This process prevents any additional gas from entering the chamber and at the same time vents the contents of the chamber. After the Panic/Abort button has been pressed, the solenoid control switches on the front panel do not function. In order to regain manual or computer control of the facility, the (black) Reset button on the front panel must be pressed.

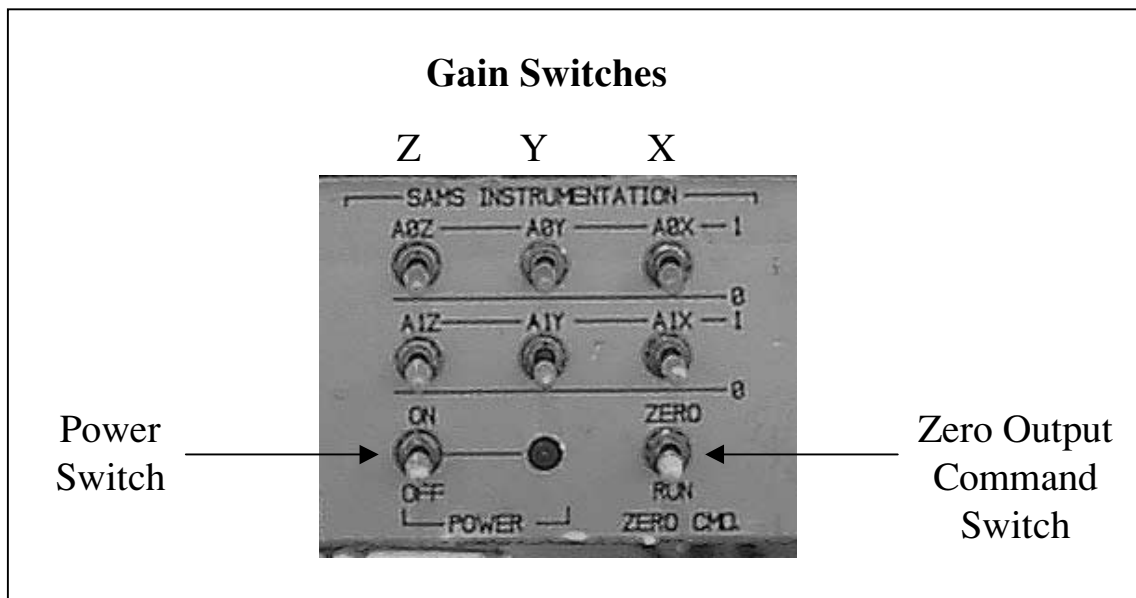


Figure 8 - Accelerometer gain control switches
(located on the main power/control panel as shown in Figure 7)

7. Data Acquisition / Control System

The Spacecraft Fire Safety Facility is equipped with a personal computer-based data acquisition and control system. This system uses a commercial software package that includes a graphical user interface that allows the user to write a custom control sequence. This software and the associated input and output hardware allow the computer to collect data and control all aspects of the experiment.

7.1 Data Acquisition / Control Hardware

The control software uses both digital and analog signals to control the hardware as shown in the schematic in Figure 9. The main input/output board is mounted in a card slot within the chassis of the PC and is connected to the analog output, analog input, temperature input and digital I/O boards. These boards are mounted within a box that is mounted on the rear of the facility. The

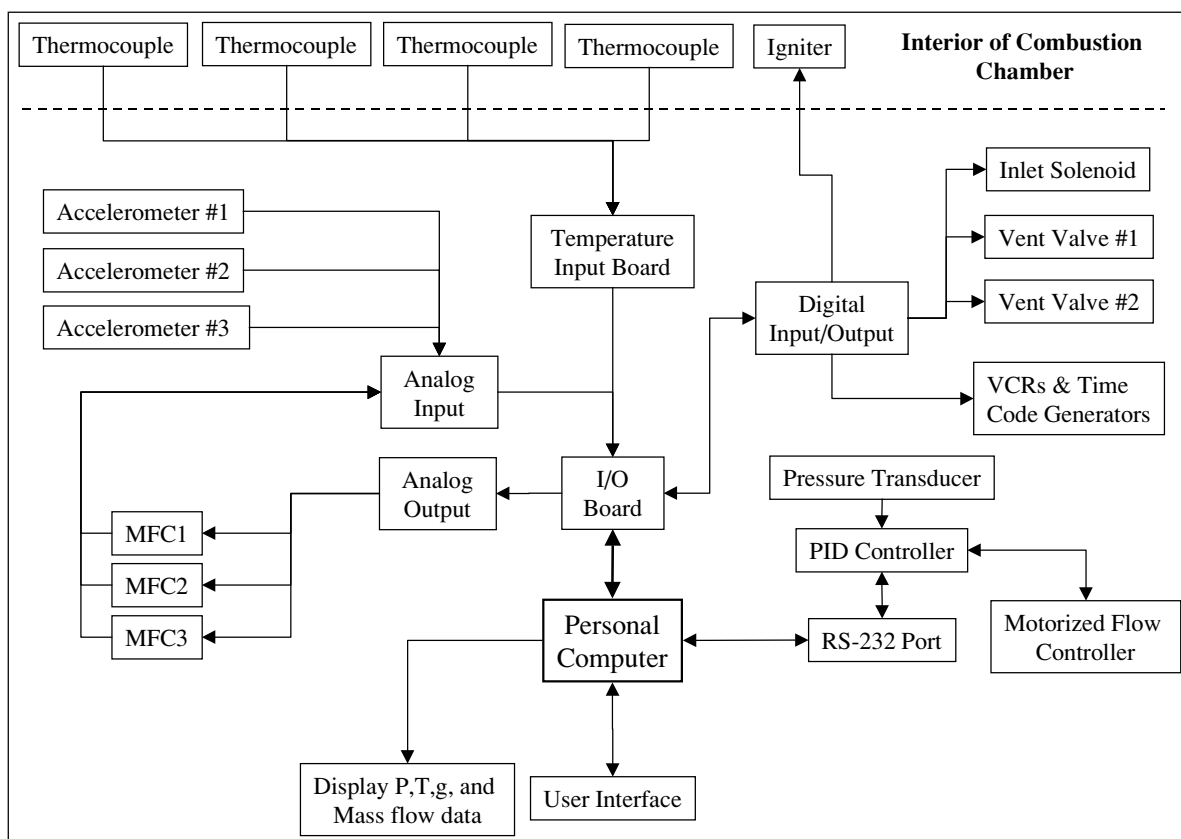


Figure 9 - Control & data acquisition schematic

layout of the boards within the box is shown in Figure 10. The analog input channels acquire the acceleration and the flow data. The analog output channels send volumetric flow values to the flow controllers. The VCRs, the time code generators, flow solenoids, and the igniter are controlled with digital relays via the digital I/O board. The digital channels are listed in Appendix C. In the current configuration, there is one available analog input, and four available analog outputs. Pressure data is read from, and commands for the motorized valve are sent to the PID controller using the computer's serial port (RS-232). Details regarding specific device I/O channels and signals are listed in Appendix C and more information about the PID controller is in presented Appendix E.

7.2 Data Acquisition / Control Software

The Spacecraft Fire Safety Facility uses the Labtech Control software package as the data acquisition and control program. This software package runs on the PC in the Windows environment, and has two main components: BUILDTIME and RUNTIME. The BUILDTIME program is the graphical interface that allows the user to design/build a custom program sequence. RUNTIME is the program that runs the program sequences created in BUILDTIME. Control sequences can be loaded into BUILDTIME; RUNTIME executes the last sequence file loaded into BIUDLTIME. Both can be run from icons in the Labtech Control (v5.03) window.

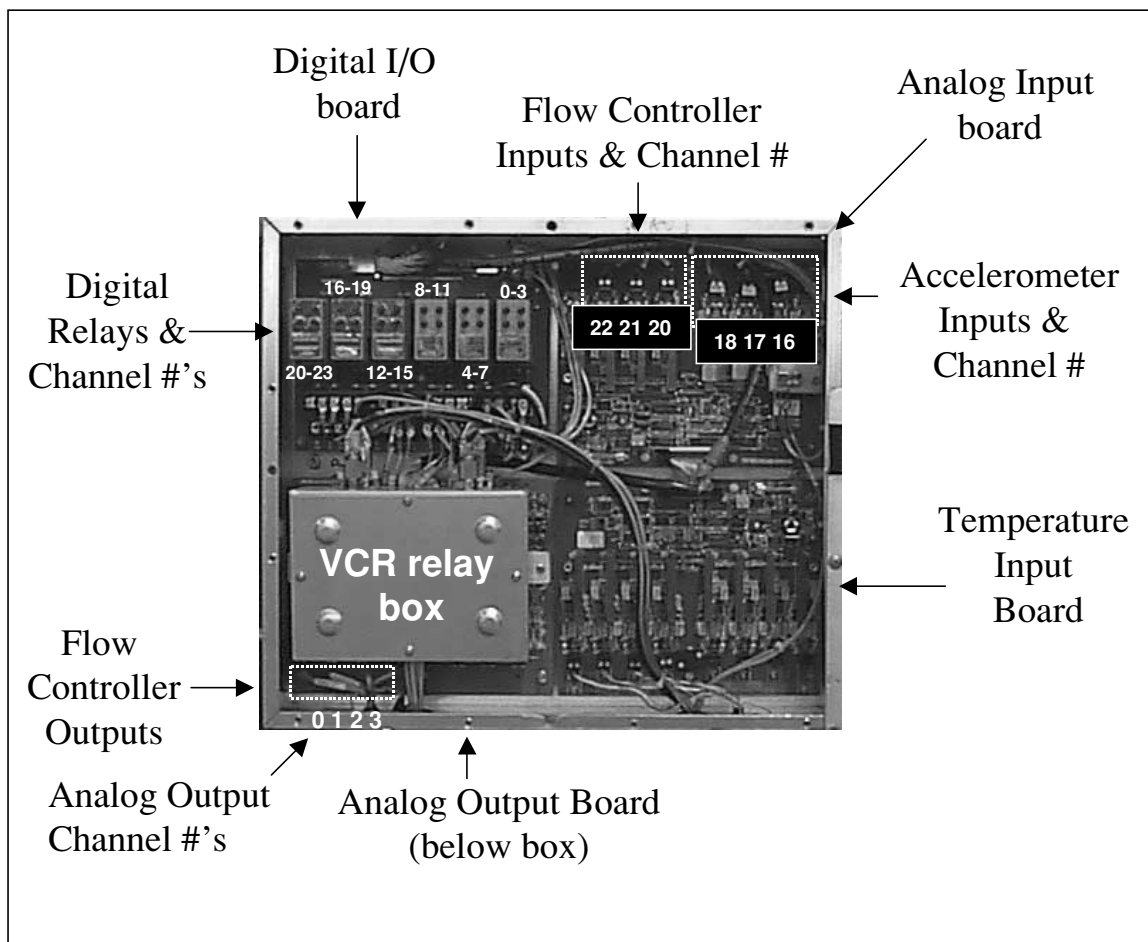


Figure 10 – Interior of the rear mounted I/O card box with a listing of the device channel numbers.

Using BUILDTIME the user creates a control program using a series of command blocks. These blocks identify the action taken by the computer. The I/O block types include analog input, analog output, digital output, RS-232 communications, and an output file. There are also blocks for: keeping time (clocks), mathematical operations and user inputs. Each block is numbered individually and has a series of control parameters that determine the block's function and operation. The list of control parameters and software logic for the data I/O blocks are shown in Figure 11. Each block can also have data written to an output file or displayed on the computer monitor. (These last two options are accomplished using the graphical interface.) In addition to the listed set of block parameters, the RS-232 block can be used to send an initialization string or a command signal to an external device, such as the PDI controller. These commands are listed in detail in Appendix E.

The source file options are required for analog and digital output blocks. These ASCII files provide the engineering values for the output command signals to the difference devices. As an example, an output block reads the data from the source file and then sends the data on a specified output channel to an output device, such as a flow controller or a digital relay. The required files for the standard control sequence are listed in Appendix D.

Each block can be started or stopped using a variety of methods that includes: starting when the program is initially run, from a user keyboard entry, or triggered by another block. The frequency of the data collected, and the frequency of command signals sent out can be varied for each block. In addition, the entire control sequence can be set to end at a given time, specified in one the scheduler menu options.

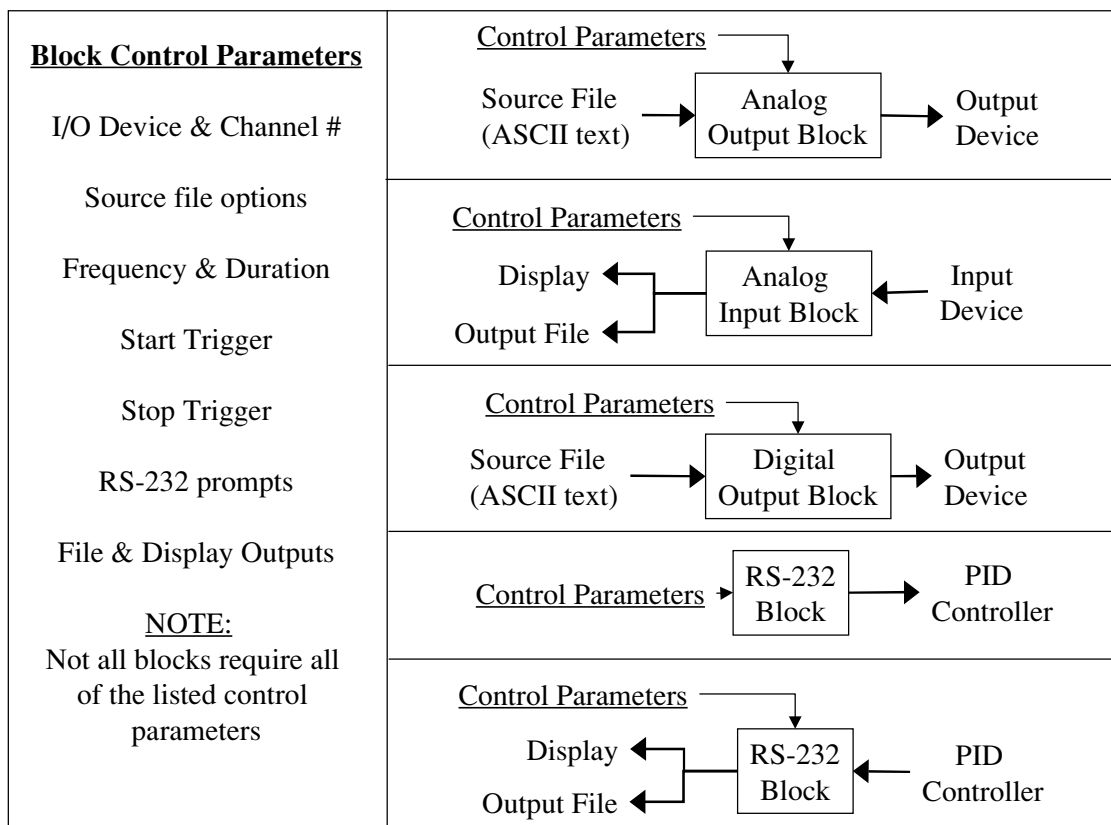


Figure 11 - Software block logic for data I/O blocks
 (Each block has a separate control parameter list)

7.3 The Spacecraft Fire Safety Facility's Control Sequence

Using this software, the computer is able to sample and record volumetric flow, chamber pressure, temperature, and tri-axial acceleration data. For this facility, the temperature, pressure and volumetric flow data are sampled at two (2) Hz and the acceleration data is sampled at 30 Hz, which corresponds to the video frame rate. During an experiment the software displays the temperature, pressure, volumetric flow, and acceleration data to the screen and writes this information to a data file on a RAM (or virtual) disk. After the test run, the data must be copied onto the computer's hard drive, otherwise the data will be lost when the computer is turned off. The data is written to the RAM disk because the process of writing data to a virtual device requires less time writing to a physical device such as a hard disk.

The standard control sequence follows the following process:

- (1) the control sequence is activated by the RUNTIME program
Note: RUNTIME always executes the last sequence file loaded in BUILDTIME
- (2) the chamber is filled to the test pressure with a small flow of gas
- (3) the sequence now waits for the facility operator to continue the experiment
- (4) the flow is restarted in the chamber, when activated by the facility operator
- (5) the operator can activate the igniter and/or vent the chamber
- (6) the experiment ends, the chamber is vented, and the control sequence ends.

This process is described in more detail in Appendix A and the Labtech block structure in detailed in Appendix B.

The Spacecraft Fire Safety Facility also has the ability to change the chamber pressure while keeping a constant velocity within the combustion chamber. This is accomplished by monitoring the chamber pressure and adjusting the volumetric flow rate. During an experiment, the program queries the PID controller for the chamber pressure and then computes the required volumetric flow rate to keep the velocity constant. The relationship between the volumetric flow rate, the gas velocity within the chamber and the chamber pressure is derived from Boyle's Law. (For more information see Appendix F.)

8. Facility Start-up and Shutdown Procedures

When starting the facility, the following procedure should be followed:

1. Turn the main power switch to the 'ON' position
2. Turn the 120 VAC switch to the 'ON' position
3. Turn the computer power switch to the 'ON' position
4. Turn the auxiliary 28 VDC switch to the 'ON' position
5. Turn the camera power switch to the 'ON' position
6. Turn the accelerometer power switch to the 'ON' position
7. Turn the igniter power switch to the 'Computer Controlled' position
8. Depress the BLACK reset button
9. Turn the solenoid control switches to the 'Computer Controlled' position (UP)

When powering down the facility, this procedure should be followed in reverse.

The Panic/Abort button on the power/control panel can be used to stop an experiment in an emergency situation. When depressed, this button automatically closes the inlet solenoid, closes vent valve #2, open relief vent valve #1, and de-energizes the igniter circuit.

9 References

9.1 Manual Listing

Labtech Control Manual

Eurotherm PID Controller manuals

Setra pressure transducer

Jordan Motorized Valve manuals

9.2 Publications/ Presentations of experiments performed using the SFSF:

Goldmeer, J., Urban, D., and T'ien, J., 1999, "The Effect of Velocity on the Extinction Behavior of a Diffusion Flame during Transient Depressurization", Joint Meeting of the United States Sections of the Combustion Institute.

Goldmeer, J.S., Urban, D.L., and T'ien, J.S., 1998, "Combustion and Extinction of PMMA Cylinders during Depressurization in Low-gravity" Fire Safety Journal, Vol. 32, No. 1., pp. 61-88.

Goldmeer, J., Urban, D., and T'ien, J., 1997, "Extinguishment of a Diffusion Flame over a PMMA Cylinder by Depressurization in Low-gravity", Fourth International Microgravity Combustion Workshop, NASA CP-10194, pp. 435-440.

Goldmeer, J., Urban, D., and T'ien, J., 1996, "Extinction of a Diffusion Flame over a PMMA Cylinder by Depressurization in Reduced-gravity", NIST Annual Conference of Fire Research, NISTIR-5904, pp. 63-64.

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Stueber, T., McCall, D., 1996, "A comparison of arc tracking tests in various aerospace environments", NASA CR 198463.

Yang, C., Goldmeer, J., Urban, D., and T'ien, J., 1994, "Combustion of a Solid Cylinder in Low Speed Flows", Fall Technical Meeting of the Eastern States Section of the Combustion Institute, pp. 47-50.

FIST presentation(s)/papers:

Appendix A – Spacecraft Fire Safety Facility – standard experiment operating procedure

This appendix describes the Spacecraft Fire Safety Facility's standard software sequence that is contained in the Labtech file SFSF-ug.LTC. This sequence is detailed in the following outline and in the flowchart in Figure A1.

A.1 Facility & Sequence Outline

- (1) Power the facility.
- (2) Depress reset button on Main Control Panel, set solenoids, etc.
- (3) Install new sample if necessary
 - a) Open pressure equalization valve (green handle) to equalize the chamber to cabin pressure.
 - b) release chamber clamp
 - c) remove chamber lid and secure on rack

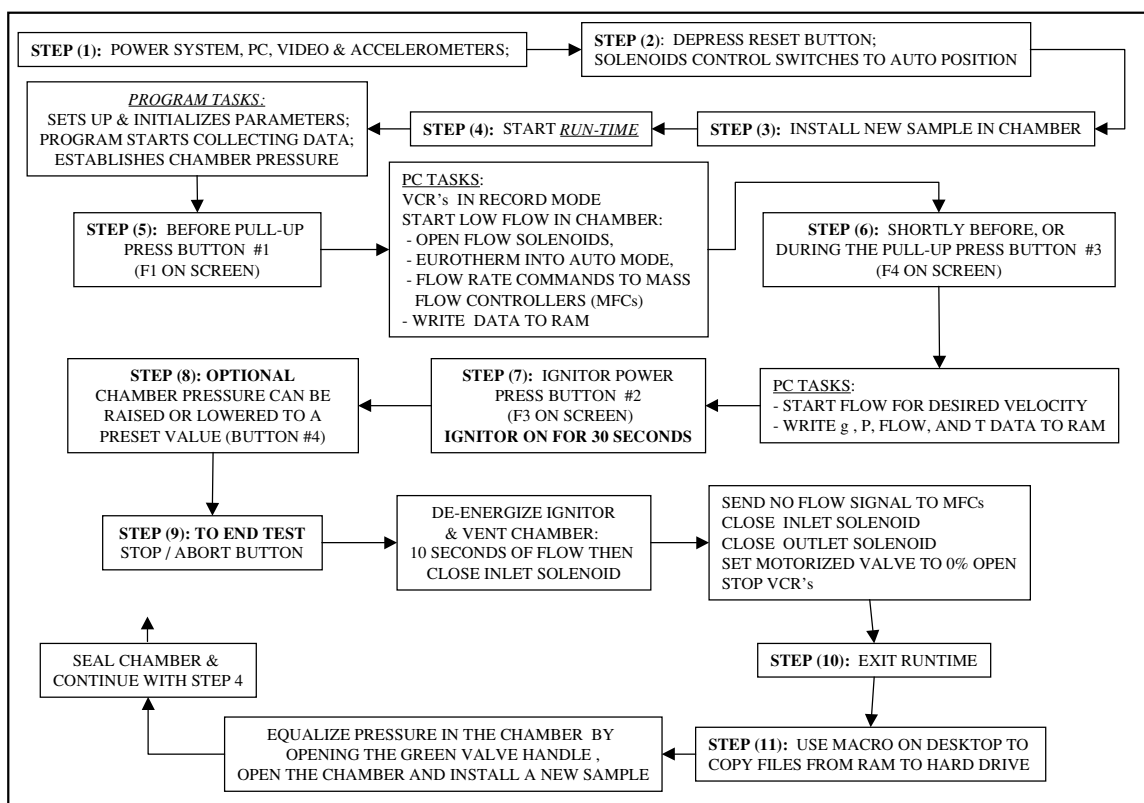


Figure A 1 – Typical experiment flowchart

- d) unplug thermocouple and igniter wire connectors
 - e) remove used sample and stow
 - f) install new sample
 - g) connect thermocouple and igniter connectors
 - h) replace chamber lid
 - i) secure chamber lid clamp
 - j) Close the pressure equalization valve
- (4) Initialize experiment & parameters - Set test pressure on the PID controller:
- a) Start experiment program. (**RUNTIME**) - this program runs the last sequence that was run in **BUILDTIME**. Before first test run BUILDTIME and load SFSF-ug.LTC, or the current experiment sequence. Make sure that the End Run Time option in the Option/Scheduler menu is set correctly, otherwise the control sequence may end abruptly.
 - b) The program automatically starts collecting temperature, pressure, g-level, and mass flow data and displays data to the screen and established the desired starting pressure.
- (5) Before the pull-up, **PRESS START BUTTON #1 (F1) or (Alt-1)** (This is not the F1 function key, but the key labeled F1 on the user buttons on the display monitor chassis.) The computer will:
- i) Put the VCRs in record mode and reset the Time Code Generators,
 - ii) Start flow in the chamber, and
 - iii) Write pressure, temperature, and mass flow data to the RAM disk (D)
- (6) Shortly before, or during the pull-up, **PRESS BUTTON LABELED Q=f(U,P) or (Alt-4)**. The computer will:
- i) start the flow for the desired chamber velocity
 - ii) begin to write the acceleration data to the RAM disk
- (7) To ignite the sample, **PRESS IGNITER BUTTON (F3) or (Alt-3)**. The computer will automatically activate the igniter for a pre-determined period of time (30 sec).
- (8) The chamber pressure can be lowered by **Vent BUTTON or (Alt-5)**. This will reduce the chamber pressure to a pre-set value, at a pre-set rate, utilizing the vacuum pump.
- (9) To stop the experiment, Press the **ABORT/STOP Button or (Alt-7)**. This automatically:
- i) stops the flow into the chamber (close mass flow controllers and inlet solenoid.)
 - ii) Open the emergency vent solenoid until the chamber completes venting. This will be followed by 10 seconds of flow from the mass flow controllers to vent any remaining combustion gases out of the chamber.
 - iii) stop the VCRs and stop recording data.
- (10) To Exit Runtime - use the **X6** key (macro)
- (11) After final test is completed power down apparatus and pump

OR

Continue with next test point at Step (3)

A.2 Emergency Procedures

A test can be stopped by using the (red) ABORT/STOP button on the user panel on the monitor chassis. When activated the computer automatically:

- (1) Closes the inlet and outlet solenoids
- (2) Open the emergency vent solenoid and vents the chamber
- (3) Flushes the chamber for 10 seconds with gas
- (4) turns off the flow from the mass flow controllers
- (5) closes the solenoids and the mass flow controller

The system also has a hardwired fail safe KILL relay system. The relay is in the safe state when it is de-energized. If the relay is de-energized, the following systems are also de-energized: the igniter, chamber inlet solenoid valve (normally closed), and the chamber vent solenoid (normally open). This KILL relay will be de-energized by any of the following events:

- (1) operator pressure the PANIC (**RED**) button,
- (2) loss of power to the relay,
- (3) loss of power to the PID controller, or
- (4) an over pressure alarm from the PID controller.

A.3 Changing the chamber velocity

The chamber velocity can be altered either at the beginning or during an experiment. This is accomplished by the following procedure:

- (1) Press (F1) key on the keyboard – this brings up a Labtech Control menu window
- (2) Use the arrow keys to scroll to the User Input Box (right side) and select this option.
- (3) Do not change the block number displayed in the window.
- (4) Use the arrow keys to scroll to the user input box.
- (5) Enter in the new velocity in units of cm/s and press RETURN
- (6) Press the (ESC) key three (3) times to return to the normal experiment displays.

This process can only be done while the program is running. The sequence default velocity is 10 cm/s. Appendix F summarizes the equations and derivations required for this process.

Appendix B – Spacecraft Fire Safety Facility Labtech Control Sequence Notes

This appendix lists the blocks used in the standard Labtech Control sequence file for the Spacecraft Fire Safety Facility. The keys used to activate different control sequences are also listed.

The initial portion of the control sequence is for filling the chamber to the desired pressure. The data is displayed to Screen #1. If the Labtech window is selected, the program should automatically switch to screen #2 for the display of the data during the remaining portion of the experiment.

B.1 Listing of standard SFSF control sequence (SFSF-ug.LTC)

These blocks are not listed in numerical order, but in the order used in the experiment sequence.

<u>Block #</u>	<u>Block Type & Function</u>
1 – 8	Type: Thermocouple, Type K, units: K Interface Device: 3 Channel: 0 Sampling Rate: 10 Hz Duration: 30 sec Start: Immediately These blocks read the temperature from the four (4) thermocouple channels during the chamber filling portion of the sequence.
10	Type: Analog input units: volts Scale factor (to get milli-g's): 100 Interface Device: 0 Channel: 17 Sampling Rate: 10 Hz Duration: 30 sec Start: Immediately This block reads the Z axis acceleration data during the filling sequence.
12	Type: Clock Sampling Rate: 30 Hz Duration: 1000 sec Start: Immediately This is the main clock for the sequence. It does not stop until the run ends or is aborted.
15, 17	Type: Analog input Units: volts (100 SLPM = 1 volt) Interface Device: 0 Channel: 20 and 21 Sampling Rate: 10,2 Hz Duration: 30 sec Start: Immediately

These blocks read the output signal from flow controllers 1 and 2 during the chamber filling portion of the sequence.

30 Type: RS-232 port command
 Sampling rate: N/A
 Duration: N/A
 Start: Immediately
 Prompt: \0040000\002SW
 This block does not call the RS-232 port. Instead, it is used to give a portion of the prompt string to put the PID controller into AUTO mode. Most of the RS-232 block commands are parsed; only input data between character number 7 and 10 is kept. The signal is sent out on com2.

31 Type: RS-232 port command
 Sampling Rate: 2Hz
 Duration: 1200 sec
 Init string: \002\003;
 Prompt: \0040000PV\005
 This block finishes the prompt call started by block 30. This block is also used to query the PID controller for the pressure in the chamber during the filling stage. The data is collected in parsed mode, the first and last characters are 7 and 10. The end-of-line character is the period (.) that has an ASCII equivalent of 46.

Blocks 1-8, 10, 12, 15, 17, 29 and 30 are started immediately. They are displayed in screen #1.

Blocks 13, 14, and 16 start 10 seconds after the sequence is started.

13 Type: Digital output
 Interface Device: 0
 Channel: 1
 Sampling Rate: 1 Hz
 Duration: 20 sec
 Start: Immediately
 Source File: Fill.txt
 This block controls the flow solenoids during the filling portion of the sequence. It reads column 3 in the file FILL.TXT as its data source. The block activates all three solenoids during the filling period, and after 20 seconds it closes the inlet solenoid and vent valve #1. The text files are preloaded and run in an open loop.

14, 16 Type: Analog output
 Units: volts (1volt = 100 SLPM)
 Interface device: 1
 Channels 0 and 1
 Duration: 20 seconds
 Start: 10 second delay after start of program
 These blocks control flow controllers 1 and 2 during the filling portion of the run. They read columns 1 and 2 during the filling portion of the run. At this point in time, no flow from controller 1, so all the columns are zero. The fill rate from controller 2 is 150 SLPM (1.5 volts). After 20 seconds the flow is turned off.

These blocks start when block 12 (the main system clock) reaches 30 seconds. So, they are activated when the main clock reaches 30 seconds.

32, 33 Type: RS-232
 Sampling Rate: 10 Hz

Duration 0.1 sec
 Prompt (block 32): \004\0000\002SW
 Prompt (block 33): >8020\0033
 These blocks are used to set the PID controller into manual mode after the chamber has been filled.

The next portion of the experiment (flow in the chamber) is activated by the user: Alt – 1

- 18 Type: Digital output
 Interface device: 0
 Channel: 0
 Sampling rate: 1 Hz
 Duration: 1000 sec
 This block starts the VCRs into record mode. It reads the file vcrr.txt as its source. The VCRs stay in record mode until the sequence times out or is stopped by the user.
- 24 Type: Clock
 Sampling rate: 30 Hz
 Duration: 3.33e-2 sec
 This block records the time that keypress (1) is entered.
- 25 Type: Calculated block:
 Operation: block 12 – block 24
 Sampling rate: 30 Hz
 Duration: 600 sec
 This block calculates the time since keypress (1)

The next set of blocks are activated when block 25 reaches 10 seconds. (There is an approximate 10 second delay time for the VCRs to start.) This is shown in the verify output as the condition "On Level" for block 25 with a trigger value 10.0. The sampled data is displayed on screen 2, which can be viewed by pressing the number 2 after the filling stage is complete.

- 20 Type: Analog input
 Units: volts
 Interface Device: 0
 Channel: 17
 Scale: 100
 Sampling Rate: 30 Hz
 Duration: 1000 sec
 This block samples the Z axis accelerometer.
- 21 Type: Thermocouple
 Units: K
 Interface device: 3
 Channel: 0
 Sampling Rate: 2 Hz
 Duration: 1000 sec
 This block samples the temperature from channel 0
- 22, 23 Type: Analog Input
 Units: Volts (1 volt = 1 SLPM)
 Interface device: 0
 Channels: 20 and 21
 Sampling Rate: 2 Hz
 Duration: 1000 sec

The blocks (22 and 23) sample data from flow controllers 1 and 2.

- 26 Type: Digital output
Interface device: 0
Channel: 2
Sampling Rate: 1 Hz
Duration: 1000 sec
Source File: TCG.TXT
This block starts the Time Code Generators which are started to be in sync with the sequence time and the time stamp written to the data files. This block reads from the file TCG.TXT as its data source.
- 27 Type: Clock
Sampling Rate: 30 Hz
Duration: 3.33e-2
This block records the time at which block 24 is at 10 seconds.
- 28 Type: Calculated block:
Operation: block 12 – block 27
Sampling Rate: 30 Hz
Duration: 1000 sec
This block is a timer for the experiment. It is zero (0) when the time code generators are started. All data files (of 30 Hz data) contain the time from this block.
- 29 Type: Digital output
Interface Device: 0
Channel: 1
Sampling Rate: 2 Hz
Duration: 1000 sec
Source File: Flow.txt
This block turns on the external lamp and opens the inlet solenoid and vent valve #2.
- 34 Type: RS-232
Interface Device: N/A
Channel: N/A
Sampling Rate: 10 Hz
Duration: 0.1 sec
Source File: N/A
These blocks are used to set the PID controller into Auto mode during the experiment. They are not used to collect pressure data from the controller.
- 35 Type: RS-232
Interface Device: N/A
Channel: N/A
Sampling Rate: 2 Hz
Duration: 1000 sec
Source File: N/A
This block queries the PID controller for the pressure. It sends the following prompt string: \0040000OV\005
It is set to receive the data on com port #2. The data from the controller is parsed; it stores the data from positions 7 – 10 of the input string.
- 41 Type: Keyboard entry
Interface Device: N/A
Channel: N/A

	Sampling Rate: 2 Hz Duration: 1000 sec Source File: N/A This block allows the user to enter in the desired gas flow chamber velocity (cm/s). The default value is 10 cm/s.
42	Type: Calculated block Operation: Constant (2.77e-4) Interface Device: N/A Channel: N/A Sampling Rate: 2 Hz Duration: 1000 sec Source File: N/A This block contains the value of the constant required in the equation $Q = P \cdot U \cdot \text{Constant}$ (See Appendix F for more detail.)
39	Type: Calculated block Operation: $(X * Y) = \text{Block 42} * \text{Block 41}$ Interface Device: N/A Channel: N/A Sampling Rate: 2 Hz Duration: 1000 sec Source File: N/A This block multiplies blocks 41 and 42. This yields Velocity * Constant
38	Type: Calculated block Operation: $(X * Y) = \text{block 39} * 35$ Interface Device: N/A Channel: N/A Sampling Rate: 2 Hz Duration: 1000 sec Source File: N/A This block multiplies blocks 39 and 35. This yields: Velocity * Constant * Pressure
40	Type: Analog Output (ECHO) Interface Device: 0 Channel: 1 Sampling Rate: 2 Hz Duration: 1000 sec Source File: N/A Start: Keypress 4 This block sends the value of block 38 as its output to the flow controller (#2). In this way the flow rate is a function of the chamber pressure. This allows the velocity within the chamber to remain constant with variations in pressure.
37	Type: Clock Interface Device: N/A Channel: N/A Sampling Rate: 2 Hz Duration: 0.5 sec Source File: N/A This block saves the time at which block 25 reaches 10 seconds.
36	Type: Calculated block Operation: $X - Y = \text{block 12} - \text{block 37}$

Interface Device: N/A
Channel: N/A
Sampling Rate: 2 Hz
Duration: 1000 sec
Source File: N/A

This block is a timer for the experiment. (It runs at 2 Hz.) It starts at the same instant that the time code generators are started. This time index is written to the file containing other 2 Hz data, such as temperature, pressure, and flow rates.

43 Type: Analog output
Interface Device: 0
Channel: 0
Sampling Rate: 2 Hz
Duration: 1000 sec
Source File: Flow.txt

This block controls flow controller #1 during the experiment. It reads column 1 from flow.txt, which is all zeros. Thus, no flow from MFC #1.

Blocks 20, 22, 35, and 36 write their data to the file d:\@-&B.dat. This filename uses Labtech output options to include the date and an incrementing number. This file contains the pressure, temperature, and flow rate data.

Blocks 9, 11, 50, and 61 are written to the file d:\@-A.dat. (This is the acceleration data.)

9, 11 Type: Analog input
units: milli-g's
scale: 100
Interface Device: 0
Channel: 16, 18
Sampling Rate: 30 Hz
Duration: 1000 sec
Source File: N/A

This block samples the thrust and yaw axis accelerometers.

44 Type: Calculated block
Operation: OFF(X)
Interface Device: N/A
Channel: N/A
Sampling Rate: 10 Hz
Duration: 0.1 sec
Source File: N/A
Start: Keypress 3

This block turns off block 29, which turned on the external lamp, opened the inlet solenoid and vent valve #2.

45 Type: Digital output
Interface Device: 0
Channel: 1
Sampling Rate: 2 Hz
Duration: 40 sec
Source File: iginter.txt
Start: Keypress 3

This block turns on the igniter for 30 seconds as well as powering all three solenoids.

46 Type: Clock
Interface Device: N/A

- Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 3.33e-2 sec
 Source File: N/A
 This block records the time at which Keypress (3) occurs.
- 47 Type: Calculated block
 Operation: Block 12 – Block 46
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 35 sec
 Source File: N/A
 This block computes the time since Keypress (3) occurred.
- 48 Type: Calculated block
 Operation: OFF(45)
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 10 Hz
 Duration: 35 sec
 Source File: N/A
 This block turns off block 45 when block 47 reaches 30 seconds. This turns off the igniter.
- 49 Type: Digital output
 Interface Device: 0
 Channel: 1
 Sampling Rate: 1e-3 Hz
 Duration: 35 sec
 Source File: Flow.txt
 This block controls the solenoids when the igniter is turned off. It is activated when block 47 reaches 30 seconds.
- 51 Type: Calculated block
 Operation: Constant (1)
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 1000 sec
 Source File: N/A
 This block is activated when Keypress 4 occurs.
- 50 Type: Calculated block
 Operation: $(X * Y) = \text{block 20} * \text{block 51}$
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 1000 sec
 Source File: N/A
 Start: Keypress 4
 This block starts writing the Z-axis data to a file. Labtech requires that all blocks writing to a file all start at the same time. Thus, the data from block 19 cannot be written to the data file with the X and Y acceleration data from blocks 9 and 11. So, a calculation block is used that has the same start time as the blocks acquiring the X and Y axis acceleration

data. Thus, this block takes the Z-axis acceleration data from block 19, multiplies it to a constant (1) and send the output to a file.

62	Type:	Calculated block
	Operation:	Constant (1)
	Interface Device:	N/A
	Channel:	N/A
	Sampling Rate:	30 Hz
	Duration:	1000 sec
	Source File:	N/A
	Start:	Keypress 4
61	Type:	Calculated block
	Operation:	block 27 * block 62
	Interface Device:	N/A
	Channel:	N/A
	Sampling Rate:	30 Hz
	Duration:	1000 sec
	Source File:	N/A
	Start:	Keypress 4
	This block takes the time from block 28, multiplies by unity and writes the result to the data file. The multiplication is required for the same reason described in block 50.	

The next set of blocks are activated by Keypress 5 (Alt -5). The main function of these blocks is to vent the chamber. The ramp rate is preset in the PID controller.

52	Type:	Calculated block
	Operation:	OFF(X)
	Interface Device:	N/A
	Channel:	N/A
	Sampling Rate:	30 Hz
	Duration:	0.1 sec
	Source File:	N/A
	Start:	Keypress 5
	This block stops block 31, which attains the pressure data, from querying the PID controller. This must be done to allow the new commands the reach the controller without interruption.	
55	Type:	Calculated block
	Operation:	ON(53,54) – this block turns on blocks 53 and 54
	Interface Device:	N/A
	Channel:	N/A
	Sampling Rate:	10 Hz
	Duration:	0.1 sec
	Source File:	N/A
	Start:	Keypress 5
53, 54	Type:	Rs-232
	Interface Device:	N/A
	Channel:	N/A
	Sampling Rate:	10 Hz
	Duration:	0.1 sec
	Source File:	N/A
	Start:	Keypress 5

These blocks send the command to place the PID controller into program mode. In this mode the controller changes the pressure according to the ramp rate parameter. The command to enter program mode is: \0040000\002OS>0112\003# . These blocks are initially turned off; they are turned on by block 55.

- 56 Type: Clock
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 3.33e-2
 Source File: N/A
 Start: Keypress 5
 This block saves the time at which Keypress 5 occurred.
- 57 Type: Calculated Block
 Operation: X – Y = block 12 – block 56
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 30 Hz
 Duration: 10 sec
 Source File: N/A
 Start: Keypress 5
 This block computes the time since keypress 5 occurred.
- 58 Type: Calculated block
 Operation: ON(31)
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 10 Hz
 Duration: 0.1 sec
 Source File: N/A
 This block turns on the RS-232 block (#31) that queries for controller for the chamber pressure. This block is activated when block 57 reaches 0.5. This allows the program mode command to reach the controller without interruption.
- 60 Type: Calculated block
 Operation: OFF(40) – turns off output to MFC2
 Interface Device: N/A
 Channel: N/A
 Sampling Rate: 10 Hz
 Duration: 0.1 sec
 Source File: N/A
 Start: Keypress 5
 This block turns off the output to MFC2. During the period in which the program is not reading the pressure data, the pressure is recorded as zero. This results in a value of zero (0) being sent to mass flow controller 2, via the analog (echo) block (#40). The problem was removed by stopping the signal from being sent to the mass flow controller; the block is turned off. When the analog output block is turned off, the flow controller retains the last output value, keeping a constant flow rate. This block is activated by Keypress 3.
- 59 Type: Calculated block
 Operation: ON(40)
 Interface Device: N/A
 Channel: N/A

Sampling Rate: 10 Hz
Duration: 0.1 sec
Source File: N/A

This block turns on the output to MFC2; it reactivates block 40. This block is activated when block 57 reaches 3 seconds. The triggering is “on level” with block 57 as the source.

The following blocks are activated when the user presses (Alt-7) Keypress 7. They stop the experiment, reset digital devices, and flush the chamber.

A second set of identical blocks is set to run after 1000 seconds, based on the timer in block 12. These block numbers are given in parenthesis.

63 (66) Type: Calculated block
Operation: OFF(1,62)
Interface Device: N/A
Channel: N/A
Sampling Rate: 10 Hz
Duration: 0.1 sec
Source File: N/A
Start: Keypress 7
This block turns off blocks 1 through 62.

67,68 (64,65) Type: RS-232
Operation: N/A
Interface Device: N/A
Channel: N/A
Sampling Rate: 10 Hz
Duration: 0.1 sec
Source File: N/A

These blocks place the PID controller into manual mode. The command in the prompt string is: \00400000\002SW>8020\0033

The command is broken up into two segments. There is no initialization string for these blocks.

69 (78) Type: Analog Output
Operation: N/A
Interface Device: 0
Channel: 0
Units: Volts
Sampling Rate: 2 Hz
Duration: 10 sec
Source File: Abort.txt

Block 78 – 1001.5 sec delay

This block stops the flow from flow controller #1. It reads from column 1 in the file abort.txt as its data file, which contains all zeros.

70 (79) Type: Analog Output
Operation: N/A
Interface Device: 0
Channel: 0
Units: Volts
Sampling Rate: 2 Hz
Duration: 10 sec

Block 79: 1001.5 sec delay on start

Source File: Abort.txt

This block resets the flow from flow controller #2 in order to flush the combustion chamber. The new value, during the flush process is 1 volt, which is 100 SLPM. The block reads column 2 in the file abort.txt. The final lines in the column are all zeros. This stops the flow from the controller.

71 (80)

Type: Digital Output

Operation: N/A

Interface Device: 0

Channel: 0

Units: N/A

Sampling Rate: 2 Hz

Duration: 15 sec

Block 80: 1001.5 sec delay on start

Source File: Abort.txt

This block stops the VCRs. It reads from column 3 in the file abort.txt.

72 (81)

Type: Digital Output

Operation: N/A

Interface Device: 0

Channel: 1

Units: N/A

Sampling Rate: 2 Hz

Duration: 10 sec

Source File: Abort.txt

This block de-energizes the external lamp and the igniter circuit. Is also closes vent #2. It keeps the inlet solenoid open and opens (relief) vent valve #1. The block reads from column 4 in the source file.

75

Type: Clock

Operation: N/A

Interface Device: 0

Channel: 0

Units: N/A

Sampling Rate: 10 Hz

Duration: 0.1 sec

Source File: N/A

This block records the time at which keypress 7 occurs.

76

Type: Clock

Operation: N/A

Interface Device: 0

Channel: 0

Units: N/A

Sampling Rate: 10 Hz

Duration: 30 sec

Source File: N/A

This clock is started by keypress 7.

77

Type: Calculated block

Operation: blocks 76 – 75.

Interface Device: 0

Channel: 0

Units: N/A

	Sampling Rate: 10 Hz Duration: 30 sec Source File: N/A This block computes the time since keypress 7 occurred.
73,74 (82,83)	Type: RS-232 Operation: N/A Interface Device: N/A Channel: N/A Sampling Rate: 10 Hz Duration: 0.1 sec Source File: N/A Blocks 82 & 83: 1006.5 sec delay on start These blocks send close command to the PID controller. The command is divided into two prompt strings in two separate blocks. The complete command is: \0040000\002XS>1100\0036 These blocks are activated when block 77 reaches 7 seconds (On Level triggering for block 77 at 7 seconds.) ALSO – blocks 82 and 83 must occur 7 seconds later than the other blocks called by the delay.
86,87 (84, 85)	Type: RS-232 Operation: N/A Interface Device: N/A Channel: N/A Sampling Rate: 10 Hz Duration: 0.1 sec Source File: N/A Blocks 84 & 85: 1010 sec delay on start These blocks end the PID controller's program mode. The command in the prompt string is: \0040000\002OS>0110\003! The command is broken up into two segments. There is no initialization string for these blocks. These blocks are activated when block 77 reaches 5 seconds. Blocks 84 and 85 must start 5 seconds later then all of the other blocks at the base delay time of 1005 seconds.
88	Type: Digital output Operation: N/A Interface Device: 0 Channel: 1 Sampling Rate: 2 Hz Duration: 1000 sec Source File: fill.txt Start: On level – when block 77 = 7 seconds
89	Type: Analog output Operation: N/A Interface Device: 0 Channel: 1 Sampling Rate: 2 Hz Duration: 1000 sec Source File: fill.txt Start: On level – when block 25 = 10 seconds

90	Type: Operation: Interface Device: Channel: Sampling Rate: Duration: Source File: Start:	Calculation OFF (89) – turn block 89 off 0 0 2 Hz 1000 sec N/A Keypress 4
91	Type: Operation: Interface Device: Channel: Sampling Rate: Duration: Source File: Start:	Calculation OFF (89 - 90) – turn block 89 and 90 off 0 0 10 Hz 0.1 sec N/A Keypress 7
92	Type: Operation: Interface Device: Channel: Sampling Rate: Duration: Source File: Start:	Digital output N/A 0 0 2 Hz 10 sec fill.txt on level: when block 77 = 7 seconds
93	Type: Operation: Interface Device: Channel: Sampling Rate: Duration: Source File: Start:	Calculation $X * Y = \text{block } 31 * 94$ 0 0 2 Hz 1000 sec fill.txt on level: when block 25 = 10 seconds
94	Type: Operation: Interface Device: Channel: Sampling Rate: Duration: Source File: Start:	Calculation Constant = 1 0 0 2 Hz 1000 sec fill.txt on level: when block 25 = 10 seconds

B.2 Keypress Guide

This section outlines the keys used to activate different control functions during an experiment run. To activate a keypress function, press the Alt key with the number, or use the defined keys below the computer monitor front panel.

1 - Start Flow

When this command is activated, the program starts the VCRs and opens the inlet solenoid. It also opens vent valve #2. After a 10 second delay (the VCRs need approximately 10 seconds to start recording), flow signals are sent to the flow controller(s). The PID controller is also placed into auto mode.

3 - Igniter Energized

When pressed, this command activates the igniter circuit for a predetermined period of time, nominally 30 seconds. Simultaneously, the external lamp is turned off. Acceleration data is now written to the RAM disk.

5 – Vent Chamber

When this command is activated, the control sequence places the PID controller into program mode. This mode activates the ramp function on the controller, which changes the chamber pressure according to the data entered via the controller's front panel. (See Appendix E).

7 - Abort

When activated, this command stops the VCRs, turns off the external lamp (if on), de-energizes the igniter (if powered), places the PID controller into manual mode, and fully closes the motorized valve. It also starts a flow at 100 SLPM to flush the combustion chamber. At the end of 10 seconds, the flow is stopped and the inlet solenoid is closed.

Appendix C - Input / Output Channels

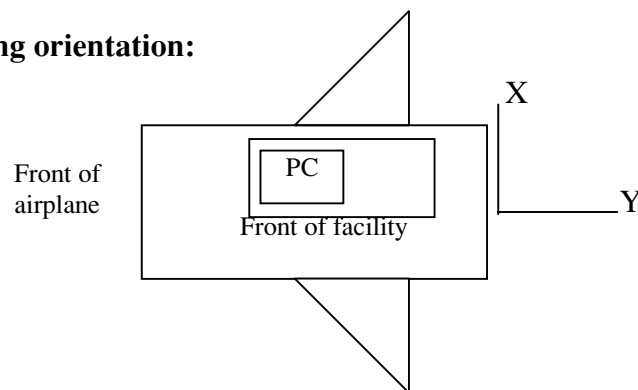
Analog Input (Device 0)

<u>Channel</u>	<u>Device</u>	<u>Voltage Range (V)</u>	<u>Engineering Variable</u> <u>Input Range</u>
17	Z-axis acceleration (positive data is g down toward floor; negative data is g upwards toward ceiling.)	0 – 5	0 to 0.5 g's
16	X-axis acceleration (Yaw axis - front to back on facility)*	0 – 5	0 to 0.5 g's
18	Y-axis acceleration (Thrust axis of airplane)*	0 – 5	0 to 0.5 g's
(Above 0.5 g's the accelerometer signal is saturated and only indicates 0.5 g's.)			
20	Flow controller 1	0 – 5	0–500 SLPM
21	Flow controller 2	0 – 5	0–500 SLPM
22	Flow controller 3	0 – 5	0–2000 SLPM

Analog Output (Device 1)

<u>Channel</u>	<u>Device</u>	<u>Voltage Range (V)</u>	<u>Engineering Variable</u> <u>Output Range</u>
0	Flow Controller 1	0 – 5	0–500 SLPM
1	Flow Controller 2	0 – 5	0–500 SLPM
2	Flow Controller 3	0 – 5	0–2000 SLPM

***Assuming the facility is in the following orientation:**



Temperature Input (Device 3)

(Channels 0 – 15)

Digital Devices

Device Location Table

<u>Device</u>	<u>channel # on board</u>
<u>VCR (#1)</u>	
Record	1
Stop	2
Pause	3
<u>VCR (#2)</u>	
Record	5
Stop	6
Pause	7
Inlet valve	9
Vent valve #1	10
Vent valve #2	11
Igniter	13
Lamp	14

** Note: there are no devices connected to channels zero (0), four (4), or eight (8).*

Digital Command Table

<u>Channel</u>	<u>Signal</u>	<u>Comments</u>
0	17	VCRs – RECORD
0	34	VCRs – STOP
1	1	Solenoid for the Inlet valve - open (powered)
1	2	Solenoid for Vent Valve #1 (Relief) – closed (powered)
1	4	Solenoid for Vent Valve #2 open (powered)
1	7	ALL SOLENOIDS POWERED
1	0	ALL SOLENOIDS DE-ENERGIZED (unpowered)
1	32	Lamp On
1	16	Igniter On
2	40	Reset time code generators

	Powered (Energized)	Unpowered * (De-energized)
Inlet Solenoid	Open	Closed
Vent Valve #2	Open	Closed
Relief (Vent Valve #1)	Closed	Open

Table C1 – Solenoid states

This is the ‘normal’ state of the solenoid. In a loss of power situation, the inlet valve and vent valve #2 close, while the relief valve (vent valve #1) opens. This prevents any additional gas from entering the combustion chamber, and allows any gas in the chamber to be vented from the facility.

Appendix D – Input (Source) Files

This appendix details the ASCII source files used by the control blocks. The files are listed in order that they are used during a normal experiment run.

FILL.TXT

This file is used by blocks when the chamber is filled to the initial pressure. (This file is setup for flow through MFC2.) Column 1 is read by the analog output block that controls MFC1 and column 2 is read by the analog output block that controls MFC2. The third column is read by the digital output block that controls the solenoid valves.

A value of (0) in column 1 or 2 represents no flow (0 volts = 0 SLPM) and a value of 1 (volt) represents a flow of either 100 or 400 SLPM, depending on which controller is being used. A value of (7) in the third column energizes all three solenoids. This opens the inlet valve, opens vent valve #1 and closes vent valve #2 (See Figure 3).

After the 20 seconds allotted for the filling (the control blocks sample the data in this file at 1 Hz), the flow controllers are sent a signal of 0 volts (no flow) that stops the inflow of gas. The digital block sends a signal of (2) that closes the inlet valve, and the vent valves.

0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	1	7
0	0	2
0	0	2
0	0	2
0	0	2
0	0	2

FLOW.TXT

This file is read by the blocks that control the flow controllers during the experiment run. The first two columns are for the mass flow controllers. The third column is for a digital block that energizes all of the solenoids and activates a lamp external to the combustion chamber. This lamp is used for viewing a sample via video prior to ignition. A value of (7) in the fourth column energizes all three solenoids. This opens the inlet valve, opens vent valve #1 and closes vent valve #2 (See Figure 3).

0	0.3	39	7
0	0.3	39	7
0	0.3	39	7
0	0.3	39	7
0	0.3	39	7
0	0.3	39	7
0	0.3	39	7
0	0.3	39	7

VCRs.TXT

This file is read by the digital output block that controls the VCRs during the actual experiment. The value of (17) places both VCRs into record mode. The file is read at 1 Hz for the duration of the experiment. (The program starts at the top of the data file after it reaches the bottom.)

17
17
17
17
17

TCG.TXT

This file is read by the digital output block that controls the time code generators during the experiment. The block needs a data point for each sampling period in the run, as the first column entry and the remaining entries are not the same. (A small portion of the file's contents are shown; the file needs to have at least 1000 rows of zeros.) The block starts the time code generators running so that the time displayed on the video matches the time stamp in the data files.

40
0
0
0
0
0
0
0
0

IGNITOR.TXT

The data in this file is read at 2 Hz by the digital block that activates the igniter circuit. The value of (23) turns on the igniter, turns off the external lamp, and keeps all three solenoids energized. Only a portion of the file is shown here. Normally, there are at least nine rows of text.

23
23
23

ABORT.TXT

The first column is read by the analog output block that controls the mass flow controller (either 1,2,or 3). A signal of zero (0) volts is sent to the MFC to stop the flow. The second column is read by the block that controls either MFC2 or MFC3, whichever is providing the gas for the forced flow. A value of (1) is sent by the computer to vent the chamber; this is a low velocity flow to remove any combustion products from the combustion chamber. Column 3 is for the digital output block to stop the VCRs. The fourth column is read by a digital output block that controls the solenoids. A value of (1) closes vent valve #1 and open vent valve #2. After the chamber is flushed, a value of (2) is sent, which closes both the inlet solenoid and vent valve #1.

The file is read at 2 Hz, so the flushing takes place in 8 seconds.

0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	1	34	1
0	0	34	1
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2
0	0	34	2

Appendix E – The PID Controller

An Eurotherm PID controller is used on the Spacecraft Fire Safety Facility to monitor and control the chamber pressure. The controller is connected to the PC via the serial port (RS-232). The controller requires a special signal protocol to send commands and receive data. This appendix summarizes the use of the controller and the special commands required to communicate with the device.

E.1 Operation of the PID controller

The controller is connected to the motorized valve located down stream of the combustion chamber as shown in the flow system schematic (Figure 3). The controller is currently set up as a valve controller with potentiometer feedback. This mode allows the controller to determine the amount the valve is open in the range of 0 to 100%. This parameter, known as the Output Parameter (mnemonic OP) describes the current position of the valve. It has a range of 0 to 100; 0% is fully closed, 100% is fully open. The controller can change the chamber pressure to match a desired pressure, by changing the flow opening within the valve. This desired pressure value is known as the set point (SP). The values of the set point, the output parameter, and the chamber pressure are displayed on the controller's front panel as shown in Figure E1.

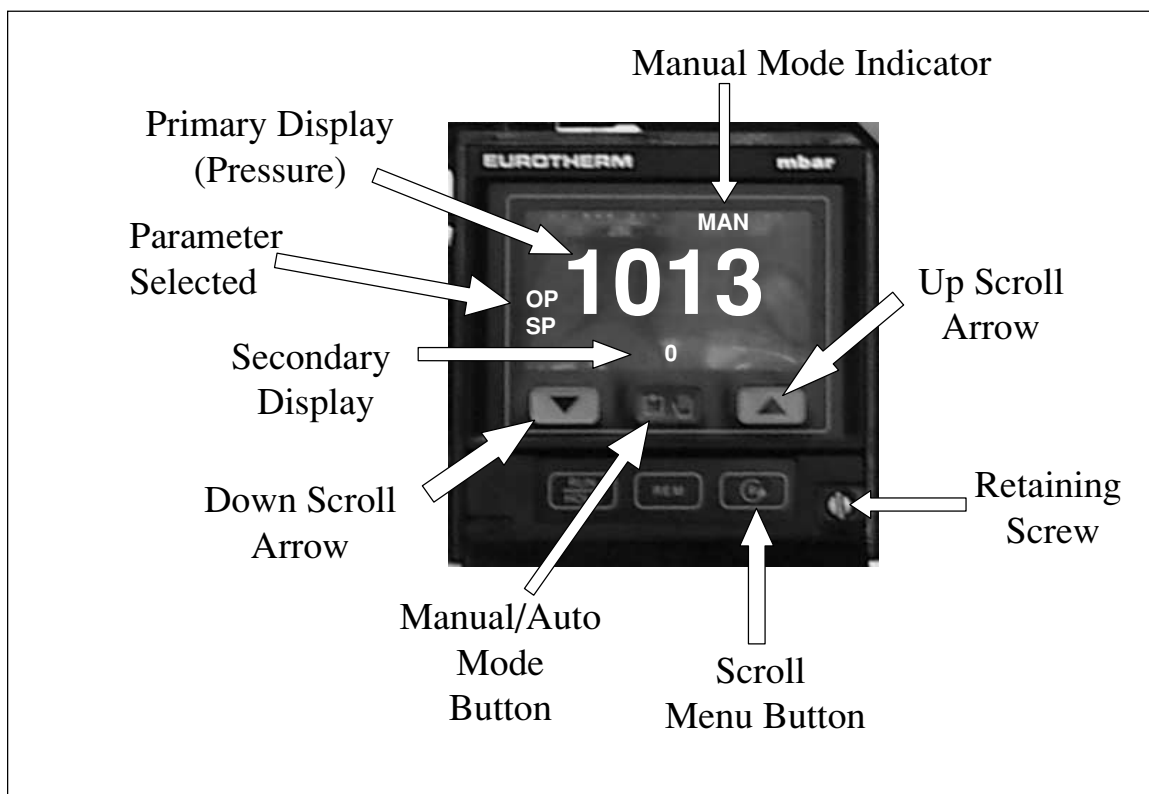


Figure E1 - PID Controller Display / Control Panel

The controller's front panel includes both a pressure display and a cluster of control buttons. The lower three buttons on the panel are normally hidden behind a small flip open door. The controller receives the output signal from the pressure transducer. This value is sent to the computer via a serial port command statement to the controller. The primary display is configured to pressure in millibars. (1 Atm = 14.7 psia = 1013 millibars). The range on the pressure transducer is 0 to 50 psia. Thus, the primary display range on the controller is 0 to 3447 millibars. *A pressure reading at or above 3447 millibars (3.4 Atm = 50 psia) activates the facility's abort sequence.*

The controller's secondary display shows either the value of the pressure set point or the output parameter as indicated by the OP or SP indicator on the left side of the panel. The set point is the pressure that the controller will try to achieve within the combustion chamber. The parameter shown by the secondary display can be toggled using the scroll button. A short duration press of this button toggles between the set point and the output parameter.

The controller can be placed into manual or auto mode by pressing the AUTO/MAN Mode button on the front panel. In manual mode, a MAN indicator is displayed at the top of the panel. This function is not required during an experiment run as the PC sets the correct mode for the controller.

The front panel also has a button for entering the scroll menu. This is required when changing an operational parameter, such as the pressure set point, or tuning the controller, which will be discussed in more detail later in this appendix.

The controller is connected to the computer via serial port # 2. The communication parameters listed in Labtech for com port 2 are: 9600 baud, even parity, 1 stop bit, and 7 data bits. The end-of-line character is a 46, which is the ASCII decimal equivalent for a period. The communication parameters as listed in the Window's control panel port setup are: 9600 baud, 8 data bits with no parity, 1 stop bit, and no flow control. The I/O address for the port is 03F8 and the interrupt channel (IRQ) is #4.

In the event that the controller has to be repaired, the controller can be removed from the wiring harness by removing the retaining screw.

E.2 Changing the Pressure Set Point

The facility operator using the command buttons on the front panel of the controller can change the pressure set point. The PC does not set this value during any point in the experiment!

To change the set point, use the following procedure:

1. If the controller is displaying the current set point pressure (SP displayed), skip to STEP (3).
2. The controller is currently displaying the value of the output parameter. Press the scroll button (for a short time) to display the set point pressure. The mnemonic SP will be displayed. If the button is pressed and held, the long scroll menu will appear. If this occurs, press and hold the scroll button until the OP value is displayed again.

3. Use the up and down arrows to change the set point pressure in millibars. As the buttons are pressed and held, the set point pressure display will change with increasing speed.

E.3 Tuning the controller

The operation of the controller/valve system can be optimized for a particular flow condition by tuning the PID controller. The (mathematical) system parameters used by the controller to maintain the pressure set point may differ as the flow rate changes. Thus, to ensure the optimal operation of the controller and obtain the desired chamber pressure, the tuning procedure should be run when the test pressure and/or flow rate change significantly between experiments.

This task **should not be performed during an actual experiment** because the PID controller will intentionally vary the chamber pressure. Ideally, this task should be performed on the ground during pre-flight testing. Tuning the controller at the experimental test conditions, will optimize the PID parameters for the given conditions. These parameters include the proportional band, integral time, and derivative time.

To tune the PID controller use the following procedure:

1. Start the experiment control software and establish the desired flow and chamber pressure.
2. Press and hold the scroll button until the mnemonic 'St' appears in the secondary display.
3. Simultaneously press both the UP and DOWN ARROW buttons.
4. The 'A-T' indicator will be illuminated on the display panel. If this does not occur, repeat steps 2 and 3.
5. The 'SP' indicator will flash for 60 seconds. During this time the pressure set point for the tuning can be changed. This is only required if the current set point is not the pressure the unit is to be tuned at.
6. After 60 seconds, the 'A-T' indicator will flash during the tuning process.
7. During the tuning process the PID controller will increase and decrease the set point in an oscillatory manner.
8. At the completion of the tuning process the controller will resume operation.

E.4 Setting the Pressure Ramp Rate

The controller can be put into a ramp mode in which the pressure can be increased or decreased to a new pressure set point. The controller can have a ramp sequence with up to eight (8) segments. Each segment consists of ramp rate, a dwell time, and a dwell level. All three parameters for each segment can be set by the facility operator through the controller's front panel. The rate can be either a constant rate in units of **millibars/minute** or a **step** change in the set point. The dwell level is the pressure set point at the end of a ramp segment. The dwell time is the amount of time that the controller will hold at a particular dwell level before initiating the next ramp segment.

The procedure for changing the ramp parameters is as follows:

1. Press and hold the scroll button until the mnemonic Pr1 appears on the display.
2. Press and release either the UP or DOWN ARROW key to display the current ramp rate.
3. Use the UP and DOWN ARROW keys to adjust the ramp rate to the desired value.

4. All other ramp segments can be found and adjusted by scrolling to the mnemonics Pr2 through Pr8
 5. Scrolling below zero yields three difference options:
 6. END – this option terminates the ramp program at the end of the previous segment.; this is required at the last step of a multi-step ramp program.
 7. STEP – immediate jump of the set point to the new value
 8. NONE – no ramp segment
 9. Press and hold the scroll button until the mnemonic P11 appears on the display.
 10. Press and release either the UP or DOWN ARROW key to display the dwell level.
 11. Use the UP and DOWN ARROW keys to adjust the dwell level to the desired value.
 12. All other dwell levels segments can be found and adjusted by scrolling to the mnemonics Pl2 through Pl8
 13. Press and hold the scroll button until the mnemonic Pd1 appears on the display.
 14. Press and release either the UP or DOWN ARROW key to display the dwell time.
 15. Use the UP and DOWN ARROW keys to adjust the dwell time to the desired value.
- Scrolling below zero gives the option END. Selecting this will end the ramp program at the end of the previous segment.

The ramp program can be initiated from the control software using **Start Button #4** on the user keypad, located on the computer monitor chassis. This will start the ramp sequence using the ramp parameters. The set point cannot be changed while the controller is in a RAMP MODE. The controller also displays on the front panel if it is RAMP or DWELL mode.

E.5 Reading Parameter Values

The correct sequence to read a parameter is :

(EOT) 0000 C1 C2 (ENQ)

in which:

- (EOT) is the beginning of transmission character; it is a Ctrl - D or ASCII 04
- **0000** is the address of the controller. The first set of zeros are the group id number (0) repeated twice. The second set of zeros are the unit id number (0) repeated twice.
- **C1, C2** are the two letters that compose the parameter mnemonic.
- **The mnemonic for pressure is PV**
- (ENQ) is the end of enquiry character; it is a Ctrl-E or ASCII 05

The controller will send back the value of the parameter you requested. As an example, the command string to obtain the current pressure is:

\004 0000 PV \005

in which the \004 and \005 represent Control-D and Control-E.

E.6 Output Parameter

This parameter (mnemonic OP) describes the current position of the valve. It has a range of 0 to 100%; 0% is fully closed, 100% is fully open. It is displayed in the secondary display along with the set point pressure. This parameter cannot be used to move (nudge), open or close the valve. Changing the position of the motorized valve requires a set of specialized commands described in the next sections.

E.7 Writing to a parameter – General Format

The correct sequence to write to a parameter is:

(EOT) 0000 (STX) C1 C2 (ABCD) (ETX) (BCC)

in which:

- **(EOT)** is the beginning of the transmission character; it is a Control-D or ASCII 04
- **0000** is the address of the controller. The first set of zeros is the group ID number (0) repeated twice. The second set of zeros is the unit ID number (0) repeated twice.
- **(STX)** is the beginning of the write portion of the command; it is a Ctrl-B or ASCII 02
- **C1 C2** - the two letter mnemonic for the control parameter
- **(ABCD)** is the new value for the parameter
- **(ETX)** is the end of the write portion of the command (end of transmission); it is a Ctrl-C or ASCII 02
- **(BCC)** is the error checking value for this sequence. It is the Exclusive Or of the characters/values from C1 to (ETX) inclusive. To compute the BCC determine the ASCII equivalent of the values/letters, convert to binary, and take the exclusive or of the components. The error checking routine requires that the BCC cannot be turned off.

E.8 Opening and closing the valve

These commands can be used to fully open or close the motorized valve, or to nudge the valve in either direction. The command sequence is:

EOT 0000 STX XS>ABCD ETX BCC

in which:

<u>command</u>	<u>action</u>	<u>BCC</u>
XS>1100	fully close motorized valve	6
XS>2100	fully open motorized valve	5
XS>3100	nudge the motorized valve (closing direction)	4
XS>4100	nudge the motorized valve (open direction)	3

E.9 Setting the mode of the controller

The write sequence is: EOT 0000 STX SW>ABCD ETX BCC

<u>command</u>	<u>action</u>	<u>BCC</u>
SW>0020	puts the controller into auto (PID) mode	; (semi-colon)
SW>8020	puts the controller into manual mode	3

E.10 Sending the control sequences from the computer to the PID controller

The command sequences are sent from the computer to the PID controller using a RS-232 block in Labtech Control. In some cases the actual command sequences are broken into multiple segments. To acquire the current chamber pressure the command sequence fits on an entire RS-232 command line. The returned data is parsed so that only the pressure data is saved; the remainder of the return signal is discarded.

Unlike reading a parameter, the PID command sequences do not fit into a single RS-232 command line, requiring that the sequence broken into two segments and sent in order by placing the commands in two consecutively numbered blocks.

Example: The command sequence for switching the PID controller to manual mode:

The entire command sequence is: \004 0000 \0020 SW>8020 \003 3

The \004, \002, and \003 represent the EOT (control-D), STX (control-B) , and ETX (control-C)

The sequence is divided into: \004 0000 \002 SW and >8020 \003 3

E.11 Parameter Notes

Depressing and holding the scroll button on the controller's front panel will command the controller to list a series of parameters. This is known as the long scroll menu. The important parameters listed in the menu are:

Scroll Parameters

A11 Alarm 1 – this is the primary display value that will cause the controller to send an alarm signal. The controller alarm is equivalent to pressing the red PANIC/ABORT button on the main control panel. The current value of this parameter is 3447 millibar.

The next three terms dictate how the controller operates the motorized valve. These are also the parameters that can be updated by tuning the controller.

Pb Proportional Band

ti	Integral time
td	Derivative time
tt	Travel time (of valve) – This is the total time in seconds (9.8) that it takes to take the valve from the fully closed position to the fully open position.
Pl	minimum valve position – this is the smallest opening that the controller can set. For this facility, this is set to zero (0) so that the controller can fully close the valve.
Ph	maximum valve position - this is the largest opening that the controller can set. For this facility, this is set to 100 so that the controller can fully open the valve.

E.12 Configuration Parameters

These are parameters that control a range of controller functions. They can be accessed via the front panel of the controller.

C2 - 0 2 2 7

This combination of the (B) and (C) digits makes the valve position act in direct mode. This means that if the pressure is greater than the set point the controller will open the valve. If the pressure is lower than the set point, the controller will close the valve. In addition, these settings configure outputs 1 and 2 such that the lower button on the front panel will move the valve to full close; the raise button will open the valve.

C3 - 1 4 0 0

The (A) digit was set to display engineering (display) units. This means that the proportional band in display units (millibars).

The (B) digit was set to be a full scale high. The alarm is activated when the display variable exceeds the alarm value.

The (C) digit was set to zero as there is no alarm 2 in the potentiometer feedback configuration.

C8 - 0 0 0 0

The (A) digit was set to no holdback as the function is not being used.

The (D) digit was set to 0. This removes all of the programmable features of the unit. It also removes all of the programming variables from the long scroll. The unit can be returned to its programming state by setting this digit to a (4).

dsl, dsh - this sets up the range for the process variable. In this case they are 0 and 3447 millibars. This corresponds to 0 and 50 psia, which corresponds to the range for the pressure transducer.

Pcl, Pch - these are the values of the potentiometer read by the controller at the limits; fully closed and fully open. The controller uses these values to create a linear scaling by which it determines the position of the valve.

Scroll Parameter Notes

tt - this is the travel time of the valve from fully closed to fully open. (It is also the time from fully open to fully closed - the valve is symmetric.)

ot - this is the minimum on time; this is the minimum time that a signal must be sent for the valve to operate. This is the minimum value allowed by the controller.

Pl, Ph - limits on the movement of the valve. These are different than the values entered in the configuration menu. These define the range of motion for the valve.

Appendix F – Derivation of Constant Velocity with Variable Pressure Equation

F.1 Derivation

A requirement for one of the experiment conducted in the Spacecraft Fire Safety Facility (SFSF) is the ability to keep a constant velocity within the combustion chamber while changing the chamber pressure . This is accomplished by monitoring the chamber pressure and adjusting the volumetric flow rate. The relationship between the volumetric flow rate, the gas velocity within the chamber and the chamber pressure is derived from Boyle's Law:

$$\frac{PV}{T} = \text{CONSTANT}$$

Equating the conditions in the mass flow controller and the chamber yields:

$$\left(\frac{PV}{T} \right)_{REF} = \text{CONSTANT} = \left(\frac{PV}{T} \right)_C$$

in which the reference state (ref) is the flow controller at standard conditions (manufacturer specification) and state (C) is the combustion chamber. Dividing both side by time yields:

$$\left(\frac{PQ}{T} \right)_{REF} = \text{CONSTANT} = \left(\frac{PQ}{T} \right)_C$$

The volumetric flow rate (Q) in the chamber is the product of the plug flow velocity and the chamber cross-sectional area. (This assumption is valid as the velocity profile within the chamber, as shown in Figure 5, is nearly constant.) The previous equation is now solved for the required flow at the flow controller. This yields:

$$Q_{REF} = P_C A_C U_C \frac{T_{REF}}{T_C} \frac{1}{P_{REF}}$$

During an experiment, the program samples the PID controller for the chamber pressure and then computes the required volumetric flow rate to keep the velocity constant. The bulk gas temperature in the chamber is assumed to be constant (293K).

The additional constants in the last equation are:

P_C = pressure in the chamber in millibar

A_C = chamber cross-sectional area = 506.7 cm²

U_C = desired chamber velocity in cm/s

$T_{REF} = 273 \text{ K}$ (assumed)

$P_{REF} = 1013 \text{ millibar}$ (assumed)

Also note that a conversion is required to get from liters/minute to $\text{cm}^3/\text{second}$, so that:

$$Q_{REF} = \frac{U_C (\text{cm/s}) (506.7 \text{ cm}^2) (P)(\text{millibar}) (273 \text{ K}) (60 \text{ sec/min})}{(293 \text{ K}) (1013 \text{ millibar}) (1000 \text{ cm}^3 / \text{liter})}$$

Thus, for MFC1 and MFC2 which have a maximum flow capacity of 500 SLPM with a 5 volt signal,

$$Q_{REF} = 0.0279 (U_C) (P_C) \text{ SLPM}$$

or
$$Q_{REF} = 2.79\text{e-}4 (U_C) (P_C) \text{ Volts}$$

For MFC3 which has a maximum flow capacity of 2000 SLPM with a 5 volt signal,

$$Q_{REF} = 0.0279 (U_C) (P_C) \text{ SLPM}$$

or
$$Q_{REF} = 6.975\text{E-}5 (U_C) (P_C) \text{ Volts}$$

The value of the volumetric flow in volts is required for the computer program, as the analog signal to the flow controller must be in volts. The difference in the coefficient for the controllers is the ratio of maximum voltage input to maximum flow rate.

To compute the maximum flow rate at any given chamber pressure (P_C), solve the flow equations for U_C , and use the maximum value for the mass flow controller, in the correct units. For example, at 1 Atm (1013 millibar), the maximum velocity in the chamber would be:

$$U_C = (Q_{REF} / P_C) (1 / 0.0279)$$

With Q_{REF} in units of SLPM. For controllers 1 or 2 ($Q_{REF} = 500 \text{ SLPM}$), the maximum velocity is 17 cm/s. For controller 3 ($Q_{REF} = 2000 \text{ SLPM}$), the maximum velocity is 70.7 cm/s.

F.2 Implementation

The process of keeping a constant gas velocity in the chamber to compensate for changes in pressure is accomplished using a series of blocks in the control sequence, as shown in Figure F1. First the pressure data is read from the PID controller (Block 35). Secondly, the facility operator enters in the desired velocity using a keyboard entry block (# 41). These values combined using one of the equations listed above to compute the required mass flow (Blocks 38, 39 and 42). This value is sent as an output using an analog echo block to the desired flow controller (Block 40). An echo block takes its input and send the data as output to the selected device. The actual block details are listed in Appendix B. In tests in which the pressure, and hence, the velocity stay

relatively constant, the pressure link can be removed (Figure F1-B). The final multiplication block (#38) uses a fixed value for the pressure (1013 millibars) instead of the experimental chamber pressure. This assumes that the experiment is to be conducted at a pressure of 1013 millibar (1 Atm).

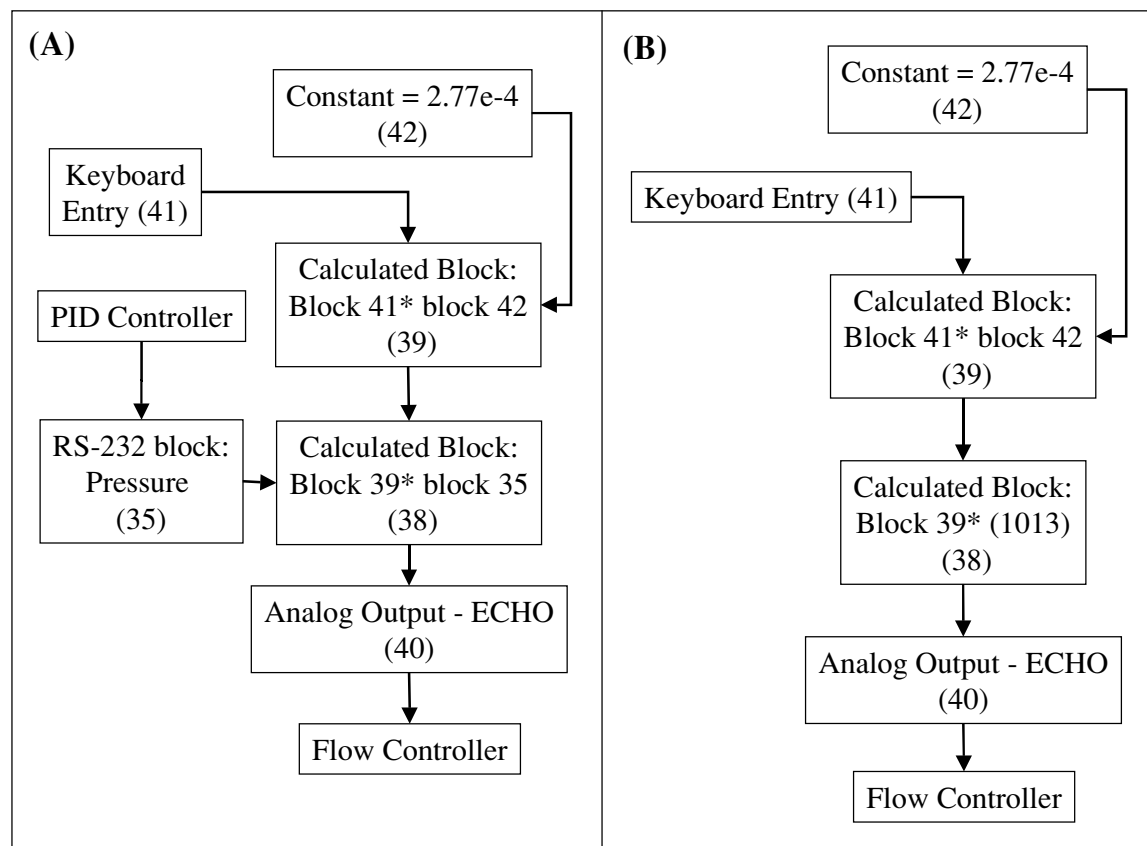


Figure F1 - Block diagram for linking pressure and chamber velocity

(Block numbers are listed in parentheses.)

Appendix G - Existing Control Sequence Files

<u>Sequence Filename</u>	<u>Description</u>
SFSF-ug.LTC	Original SFSF control sequence. The igniter is powered for 30 seconds Maximum runtime: 1000 seconds The chamber velocity <u>IS</u> linked to the chamber pressure.
CM-1.LTC	Simpler version of SFSF-ug sequence. However, there is no capability for venting and the velocity <u>IS NOT</u> a function of the chamber pressure. (This sequence is intended for simple low-pressure tests at 1g.)

FIST4.LTC

Variation on SFSF-ug.LTC:

- The igniter is powered for 30 seconds
- The flow system uses flow controller #2
- Maximum runtime: 4000 seconds
- The chamber velocity **IS NOT** linked to the chamber pressure.
(The program assumes the chamber pressure is 1013 millibars.)

FIST5.LTC

Variation on SFSF-ug.LTC:

- The igniter is powered for 30 seconds
- The flow system uses flow controller #2
- Maximum runtime: 4000 seconds
- The chamber velocity **IS** linked to the chamber pressure.

FIST6.LTC

Variation on SFSF-ug.LTC:

- Once energized, the igniter is not de-energized during the test; the igniter can be toggled on and off using the igniter control switch on the main control panel.
- The flow system uses flow controller #3
- Maximum runtime: 4000 seconds
- The chamber velocity **IS NOT** linked to the chamber pressure.
(The program assumes the chamber pressure is 1013 millibars.)

Appendix H – Output Files

The Labview control sequence creates two output files for each test; one file contains time and acceleration data (A), and the other (B) contains the time, pressure, temperature and mass flow data. The file name includes a date stamp (MMDD) and a numerical counter for tests performed on that date. The counter restarts at zero for each new test date. Typical output file names are:

0629-b0.dat - This was the first (B) file created on June 29 (06/29)

0629-b1.dat - This was the second (B) file created on June 29 (06/29)

1015-a2.dat - This was the third (A) file created on October 15 (15/15)

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13. ABSTRACT (Maximum 200 words) The Spacecraft Fire Safety Facility (SFSF) is a test facility that can be flown on NASA's reduced gravity aircraft to perform various types of combustion experiments under a variety of experimental conditions. To date, this facility has flown numerous times on the aircraft and has been used to perform experiments ranging from an examination of the effects transient depressurization on combustion, to ignition and flame spread. A list of publications/presentations based on experiments performed in the SFSF is included in the reference section. This facility consists of five main sub-systems: combustion chamber, sample holders, gas flow system, imaging system, and the data acquisition/control system. Each of these subsystems will be reviewed in more detail. These subsystems provide the experiment operator with the ability to monitor and/or control numerous experimental parameters.				
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